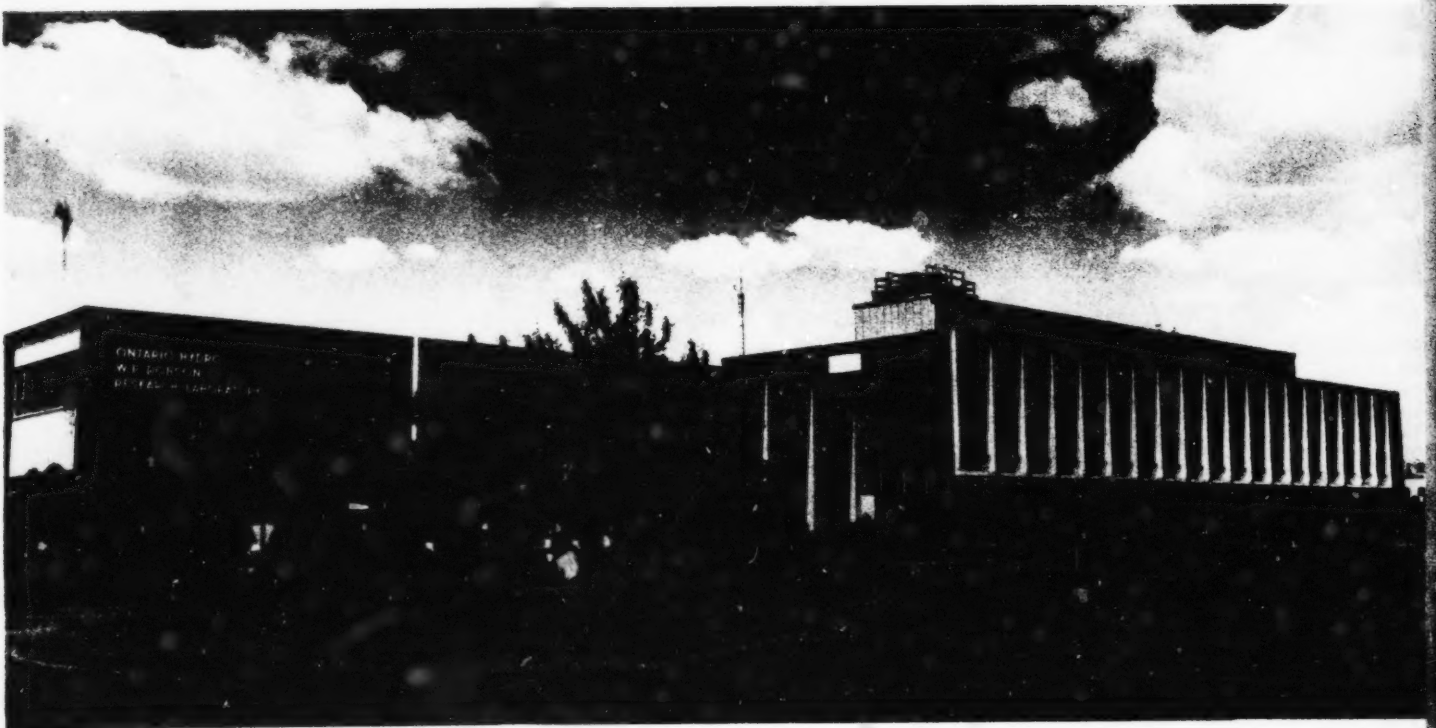
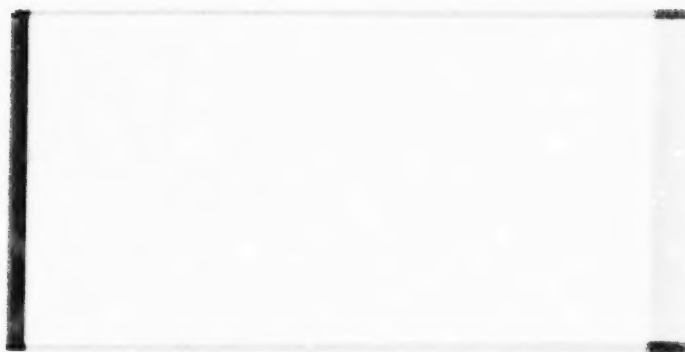




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RESPONSES OF ALEWIFE AND SMELT TO
AIR BUBBLES ALONE AND COMBINED
WITH LIGHTS

Report No 83-266-K

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ABSTRACT

The responses of fish to air bubbles and lights were investigated under laboratory conditions. In these tests, diameter of the hole opening in the bubble wand was used to indicate bubble size. For alewife under low level light, size of hole opening significantly influenced fish behaviour. The highest overall reduction in fish passage (84%) through a bubble barrier was achieved with the largest hole opening (5 cm). Hole opening in the bubble wand did not appear to significantly influence smelt behaviour. Alewife and smelt responses to different horizontally spaced bubbles did not vary significantly. In the alewife tests, effectiveness of air bubbles in reducing the number of fish passages was reduced considerably in the absence of light. Preliminary tests indicated that white and red filtered incandescent light may offer an attractive alternative to strobe light when combined with air bubbles as an exclusion scheme.

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TABLE OF CONTENTS

	<u>Page</u>
A. INTRODUCTION	1
B. MATERIALS AND METHODS	
1. Species Investigated	2
2. Bubble Wand	2
3. Experimental Procedure	2
4. Statistical Analysis	5
C. RESULTS AND DISCUSSION	
1. Smelt	5
1.1 Typical Behavioural Patterns	5
1.2 Effect of Bubble Size and Horizontal Spacing on Smelt Behaviour	6
1.3 Time Interval at which Passages and Encounters Occurred	8
2. Alewife	9
2.1 Typical Behavioural Patterns	9
2.2 Effect of Bubble Size and Horizontal Spacing on Alewife Behaviour	9
2.2.1 Low Level Light Tests	9
Passages - Results and Discussion	9
Encounters - Results and Discussion	11
2.2.2 Night Simulated Tests	12
Passages - Results and Discussion	12
Encounters - Results and Discussion	12
2.3 Time Interval at which Passages and Encounters Occurred - Results and Discussion	15
2.4 Effectiveness of a Combined Light/Air Bubble Screen in Fish Exclusion	15
D. CONCLUSIONS	21
E. RECOMMENDATIONS	23
REFERENCES	24
APPENDIX A	25
B	28
C	30
D	33
DISTRIBUTION	last page

LIST OF FIGURES

		<u>Page</u>
Figure 1A	Diagram of Bubble Wand	3
1B	Experimental Tank Used in Bubble Tests	3
Figure 2	Typical Swimming Patterns Displayed by Smelt and Alewife	7
Figure 3	Effects of Bubble Size and Spacing on the Number of Alewife Passages and Encounters Relative to Controls (Low Level Light Tests)	10
Figure 4	Effects of Bubble Size and Spacing on the Number of Alewife Passages and Encounters Relative to Controls (Night Simulated Tests)	13
Figure 5	Comparison of Effectiveness Between Red, White and Blue Incandescent Light when Combined with Air Bubbles in Excluding Alewife (0.6 m hole opening, 5 cm spacing)	18
Figure 6	Comparison of Effectiveness Between Red, White and Blue Incandescent, and Strobe Light when combined with Air Bubbles in Excluding Alewife (5.0 cm hole opening, 20 cm spacing)	20

LIST OF TABLES

		<u>Page</u>
Table 1	Various Hole Openings and Bubble Spacings Used in Experimental Design	4
Table 2	Comparison of the Number of Smelt Passages (0.0 m) and Encounters (0.6, 1.2 m Distance Lines) for Various Hole Sizes and Bubble Spacings	6
Table 3	Results of Analyses of Variance Statistics (One-Way) Comparing the Mean Time Interval at Which Most Smelt Passages (0.0 m) and Encounters (0.6, 1.2 m) Occurred for Each Test Condition (Low Level Light)	8
Table 4	Multiple Range Tests Comparing the Role of Hole Opening as a Factor Affecting Alewife Behaviour Under Low Level Light	11
Table 5	Multiple Range Tests Comparing the Role of Hole Opening as a Factor Affecting Alewife Behaviour Under Simulated Night Conditions	14
Table 6	Results of Analyses of Variance Statistics Comparing the Mean Time Interval at which Most Alewife Passages (0.0 m) and Encounters (0.6, 1.2 m) Occurred for Each Test Condition	16
Table 7	Multiple Range Tests Comparing the Effectiveness of Red(R), Blue(B) and White(W) Incandescent, and Strobe(S) Light Combined with Air Bubbles to Bubbles Alone (BA) In Excluding Fish	19
Table 8	Results of Analyses of Variance Statistics Comparing the Mean Time Interval at which Most Alewife Passages (0.0 m) and Encounters (0.6, 1.2 m) Occurred for Each Light Test	22



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To Dr. W.R. Effer
Environmental Studies
and Assessment
Design and Development
Division

RESPONSES OF ALEWIFE AND SMELT TO AIR BUBBLES ALONE AND COMBINED WITH LIGHTS

INTRODUCTION

As part of the Capitalized-Once-Through-Cooling Program (COTC), Environmental Studies and Assessment requested the Biological Research Section to research and develop various fish diversion schemes as retrofit possibilities for incorporation into the design of once-through-cooling systems. Preliminary laboratory work on air bubbles indicated that air bubbles are effective in diverting fish in sections of experimental tanks and show promise in a fish diversion scheme (Ontario Hydro Research Division Report No 82-362-K). However, the optimum size of bubbles and spacing was not known.

Illumination was needed to increase effectiveness of the bubble screen at night or when visibility was reduced. A combined strobe light and bubble scheme was effective under laboratory conditions (Ontario Hydro Research Division Report No 82-362-K). However, serious reliability problems associated with this light source in field tests suggested that more reliable alternatives would be desirable (Ontario Hydro Research Division Report No C82-19-K).

A systematic study was undertaken to investigate the responses of fish to different sizes of air bubbles spaced at various horizontal distances, and to determine the effectiveness of combining illumination with air bubbles as an exclusion scheme. Based on this study, recommendations will be made on the optimal design of an air bubble system for field evaluation.

MATERIALS AND METHODS

1. Species Investigated

Test organisms were alewife (*Alosa pseudoharengus*) and smelt (*Osmerus mordax*). Both species were collected with beach seines at Pickering GS during the spring and summer of 1982. Smelt ranged in size from 8 to 11 cm and alewife varied from approximately 11 to 16 cm.

Prior to experimentation, fish were held for at least 48 h in either a 3.6 m circular pool (~1.0 m depth) or a 4.5 x 9.1 m oval pool (~1.0 m depth) under a natural photoperiod of 10-14 h of light. Water temperatures ranged from approximately 9.5 to 13°C. Both species were not fed during the course of the experiments.

2. Bubble Wand

Air flow was directed from a manifold feed system to individual fittings positioned on the pool bottom (Figure 1A). The number of fittings could be adjusted to obtain the desired experimental criterion. The diameter of the hole openings of each fitting was used as a basis for estimating bubble size although bubbles broke immediately following release, into smaller components during ascent. No attempt was made to measure these smaller components. Hole sizes (diameter) of the bubble wand ranged from approximately 0.6 cm (0.25 in) to 5.0 cm (2.0 in). Air lines were positioned along the edge of the pool, and were not observed to influence fish behaviour. The length of the wand was approximately 1.2 m. Air pressure used in these tests was ~5 kp. The bubble stream was continuous for each hole diameter tested.

3. Experimental Procedure

The experimental procedure and design were similar to those used in previous air bubble behavioural tests (Ontario Hydro Research Division Report No 82-362-K) and were conducted in a large oval pool (Figure 1B). The experimental zone was approximately 5.5 m in length, 1.5 m in width, and approximately 1.0 m in depth. Fish were directed with current, and their behaviour in response to bubble openings of different size and horizontal spacings was determined (Table 1). Because of availability problems, tests with smelt were done using hole openings of 0.6, 2.5 and 5.0 cm diameter, spaced 5 or 20 cm apart under low level light. Alewife tests were conducted under both low level light (<10 lux, <0.02 $\mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), and simulated night conditions (light not measurable), and included evaluating four hole openings (0.6, 1.3, 2.5, 5.0 cm) and three bubble spacings (5, 10, 20 cm). In the dark tests, 2.5 cm hole openings were not evaluated.

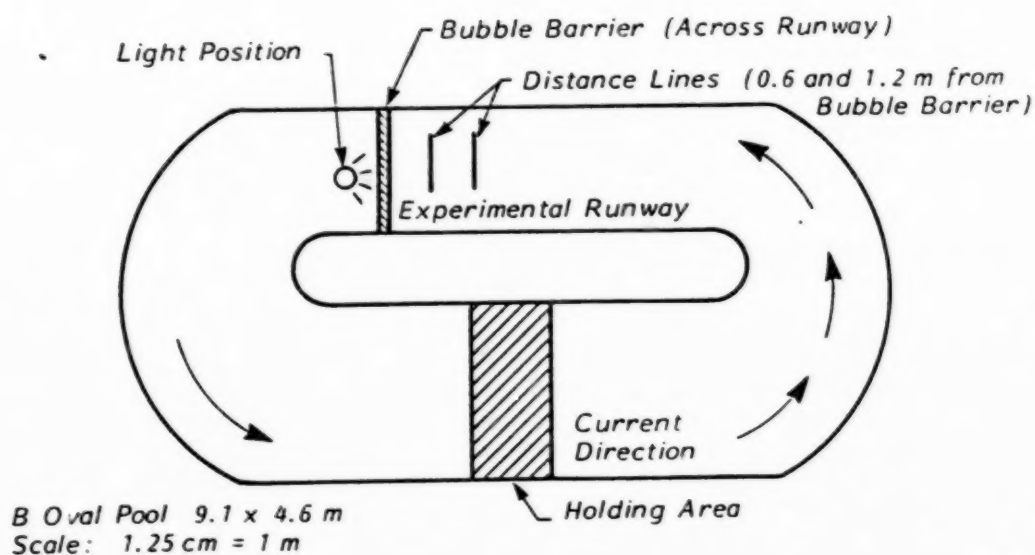
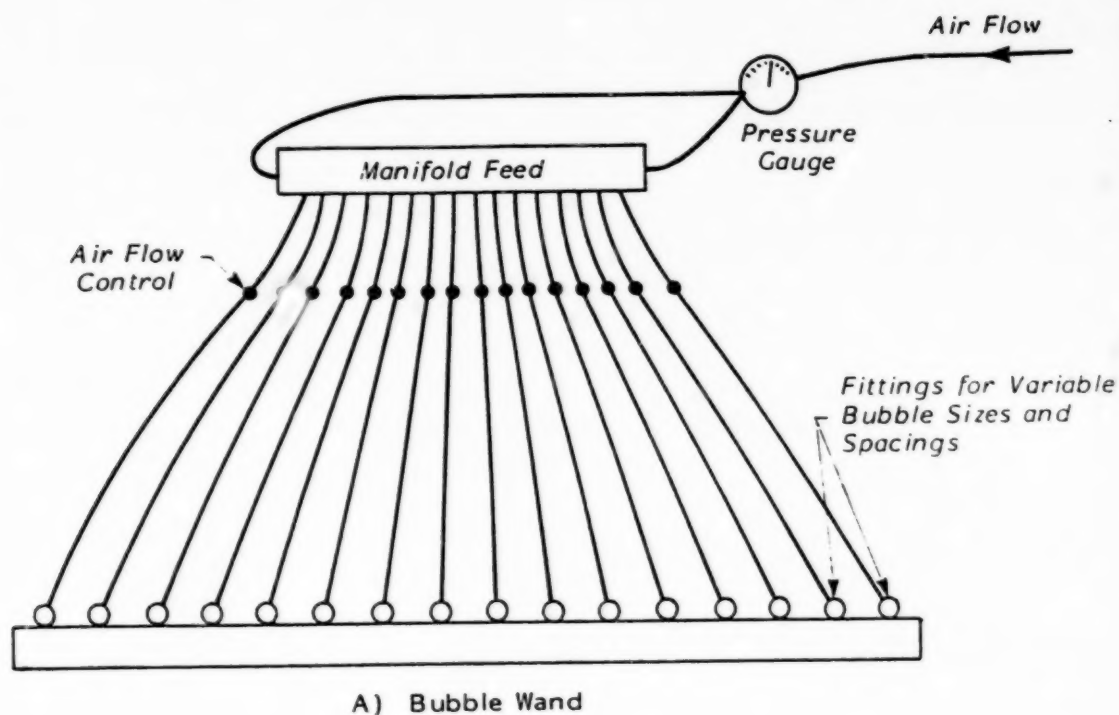


FIGURE 1A - DIAGRAM OF BUBBLE WAND

FIGURE 1B - EXPERIMENTAL TANK USED IN BUBBLE TESTS

All tests were conducted at a current velocity of approximately 0.2 m.s^{-1} and were monitored over a 30-minute period using both closed circuit TV and visual observation.

TABLE 1
VARIOUS HOLE OPENINGS AND BUBBLE
SPACINGS USED IN EXPERIMENTAL DESIGN

<u>Species</u>	<u>Light Condition</u>	<u>Hole Opening (cm)</u>	<u>Bubble Spacing (cm)</u>
Smelt	Low Level Light	0.6, 2.5, 5.0	5, 20
Alewife	Low Level Light	0.6, 1.3, 2.5, 5.0	5, 10, 20
	Dark	0.6, 1.3, 5.0	5, 20

Five replicated experiments were performed, each with 50 fish, and the following criteria were monitored. Fish which appeared unhealthy were replaced.

- (i) Number of fish passing through the bubble screen. Estimates were determined at five-minute time intervals. The number of fish passing through the barrier was expressed as a per cent reduction (or effectiveness) relative to corresponding control tests (ie absence of barrier, alewife only).
- (ii) Number of encounters 0.6 and 1.2 m from the barrier. These estimates refer to the number of fish which approached and passed over each distance line. No distinction was made between single or multiple encounters by groups of fish. Similar to passage results, estimates were made at five-minute intervals over the monitoring period.
- (iii) Description of the swimming patterns displayed by fish in the runway as they approached the barrier.

Control tests were conducted for alewife by monitoring fish movement and distribution in the experimental zone in the absence of a bubble barrier. Controls were 30 minutes in duration, and were conducted under both low level light ($<10 \text{ lux}$, $<0.02 \text{ }\mu\text{E.m}^{-2}.\text{s}^{-1}$) and dark conditions. Since alewife were generally in poor condition (somewhat lethargic) a different set of controls (five replicates) was conducted prior to or immediately following an experimental group of tests (a total of 70 controls). Control tests for smelt were not completed because of fish availability problems although they appeared to be in good condition.

Additional tests involving alewife only were conducted to determine the effectiveness of combining light with air bubbles. Blue, red and white illumination (incandescent) were used in these tests. The red filter used transmits visible light from approximately 600 to 800 nm (infrared, red, orange and yellow regions; Ontario Hydro Research Division Report No 78-516-K). The blue filter has two transmittance peaks, one through the yellow, green, blue and violet regions (400 - 580 nm) and the other through the infrared (>750 nm). The spectral distribution curve for white incandescent had a large percentage of the energy in the orange and red regions of the visible spectrum (597-735 nm).

The single light source was used in each test and was submerged and placed approximately 0.6 m behind the bubble barrier (Figure 1B). Intensities of white incandescent light measured as illuminance (lux) ranged from a mean of approximately 151 lux (60-350) on the bubble barrier to approximately 25 lux (23-29.5) 1.2 m from the barrier. Blue light intensities were of similar magnitude while red light levels were about one-half that of white light on the bubble screen. Red light levels were not measurable 1.2 m from the bubble screen.

The experimental design using different light sources was similar to that for air bubbles only. The effectiveness of filtered red, blue and white incandescent light sources in diverting fish was tested for both 0.6 cm (spaced 5 cm apart) and 5 cm (spaced 20 cm apart) hole openings. In addition, a combined (white) strobe light/air bubble barrier was also tested with a 5 cm hole opening and 20 cm spacing. Strobe light intensities were lower than white incandescent light (<15 lux, <0.20 $\mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$; Ontario Hydro Research Division Report No 82-362-K). Controls (15 replicates) were conducted between experimental (light) tests.

4. Statistical Analysis

Since alewife condition was generally poor throughout the experimental period, all experimental data were standardized relative to each set of corresponding controls prior to analysis (ie a ratio of # fish exp/# fish control). All data (smelt and alewife) were analyzed using analysis of variance. Data were transformed (log) to satisfy the assumption of homogeneity of variance. ANOVA tables are listed in Appendices A, B and C. Multiple range tests (S.N.K.) are included as test tables. The vertical bars accompanying mean estimates in all figures are standard deviations.

RESULTS AND DISCUSSION

1. Smelt

1.1 Typical Behavioural Patterns

Casual observations indicated that smelt showed a preference for the experimental zone, and displayed a typical rheotactic response in the absence of air bubbles. In the presence of an air bubble

curtain, smelt displayed three distinct behavioural patterns; avoidance, direct passage, and accumulation (Figure 2). Direct passage was observed when smelt passed directly through the air bubble curtain. As fish entered or passed through the air bubbles, there was a noticeable increase in swimming speed, and some dis-orientation. Avoidance behaviour consisted of fish avoiding the air bubble screen. Accumulation consisted of fish accumulating within a few metres of the system (pattern three), and oriented against the current flow. Fish accumulation was also noted in the absence of bubbles but not to the same extent as observed with bubbles present.

1.2 Effect of Bubble Size and Horizontal Spacing on Smelt Behaviour

Since control tests were not conducted, an estimate of the overall effectiveness of the bubble system in reducing smelt passage could not be made. However, a measure of the number of smelt passing through the bubble screen was expressed relative to the number of encounters 0.6 and 1.2 m from the barrier (Table 2, Appendix A). For various hole openings, there was an overall reduction of approximately 43 and 52% in fish passages relative to fish which entered the 0.6 and 1.2 m distance lines, respectively.

TABLE 2
COMPARISON OF THE NUMBER OF SMELT PASSAGES (0.0 m)
AND ENCOUNTERS (0.6, 1.2 m DISTANCE LINES) FOR
VARIOUS HOLE SIZES AND BUBBLE SPACINGS*

Comparison	Hole Opening (cm)**			Spacing (cm)***	
	0.6	2.5	5.0	5	20
Passages	33.7	14.3	22.7	20.9	26.3
Encounters:					
0.6 m Distance	58.8	29.1	36.2	49.3	33.5
1.2 m Distance	77.2	36.0	34.3	58.6	39.7
Per Cent Remaining*			Per Cent Remaining*		
0.6 m encounter	42.6	50.8	37.3 $\bar{x}$ 43.0	57.6	21.5 $\bar{x}$ 43.0
1.2 m encounter	56.3	60.3	33.8 $\bar{x}$ 52.1	64.3	33.7 $\bar{x}$ 52.0

* Per Cent Remaining:

$$\frac{\# \text{ encounter} - \# \text{ passage}}{\# \text{ encounters}} \times 100$$

** averaged over all spacings

*** averaged over all hole openings
- 6 -

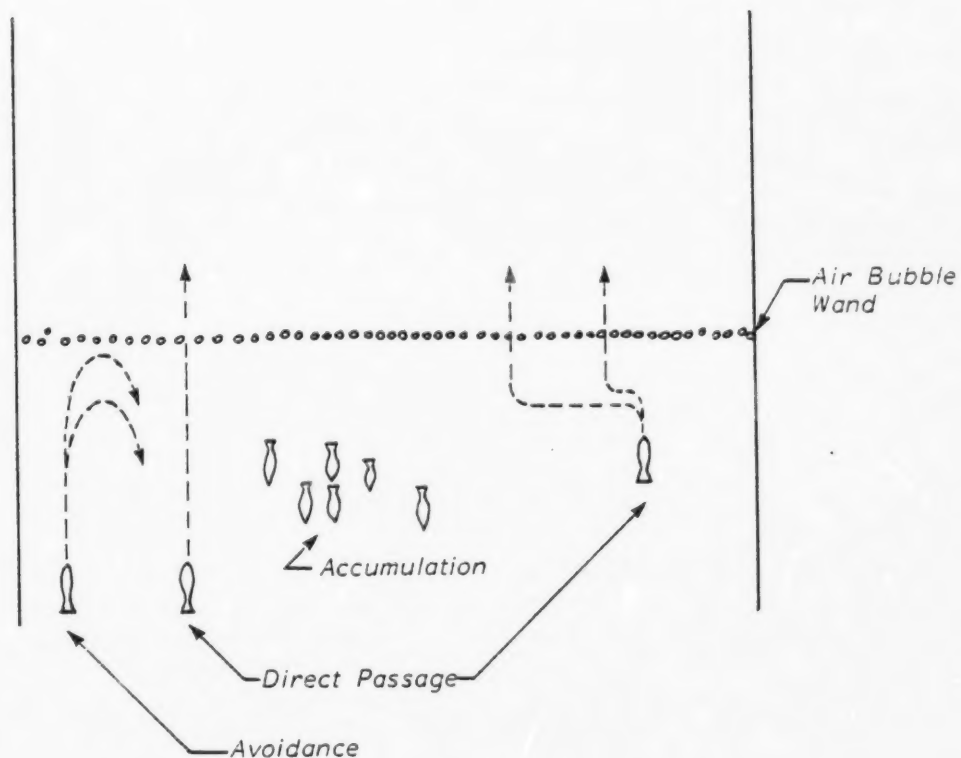


FIGURE 2
TYPICAL SWIMMING PATTERNS DISPLAYED
BY SMELT AND ALEWIFE

When expressed in terms of spacing, there was a reduction of approximately 43 and 52% in fish passages relative to encounters at the 0.6 and 1.2 m distance lines, respectively (Table 2).

The number of smelt passages was compared statistically with respect to hole opening in the bubble wand (bubble size) and horizontal spacing of the air bubbles. There was no consistent trend between the number of fish passages and size of hole opening ($F_{2,24} = 1.33$, $p > 0.05$), or horizontal bubble spacing ($F_{1,24} = 0.2$, $p > 0.05$). Analysis of the data on the number of smelt encounters 0.6 and 1.2 m from the air bubble barrier showed similar results (Appendix A).

1.3 Time Interval at which Passages and Encounters Occurred

Data were analyzed with respect to the time interval (0,5,10,15,20, 25,30 minutes) at which most of the smelt passages and encounters were recorded (Table 3).

TABLE 3

RESULTS OF ANALYSES OF VARIANCE STATISTICS (ONE-WAY)
COMPARING THE MEAN TIME INTERVAL AT WHICH MOST SMELT
PASSAGES (0.0 m) AND ENCOUNTERS (0.6, 1.2 m)
OCCURRED FOR EACH TEST CONDITION (LOW LEVEL LIGHT)

Comparison	Hole Size (cm)	Bubble Spacing (cm)	d.f.	F-Statistic	Multiple Range Test Lowest-Highest Numbers
1.2 m distance line (encounter)	0.6	5	5,24	0.87	-
		20	5,24	0.46	-
	2.5	5	5,24	4.25	-
		20	5,24	1.22	-
	5.0	5	5,24	0.23	-
		20	5,24	0.55	-
0.6 m distance line (encounter)	0.6	5	5,24	0.24	-
		20	5,24	0.24	-
	2.5	5	5,24	4.79*	-
		20	5,24		-
	5.0	20	5,24	2.08	-
		5	5,24	1.16	-
passages	0.6	5	5,24	0.23	-
		20	5,24	0.58	-
	2.5	5	5,24	1.49	-
		20	5,24	0.09	-
	5.0	5	5,24	0.43	-
		20	5,24	0.39	-

30 15 25 20 5 10
(time interval min)

Generally, there was no indication of a change in smelt passage or encounters as the monitoring progressed. The only exception was the number of encounters recorded at the 0.6 m distance line for the 2.5 cm hole opening test results. Highest number of encounters appeared to occur within the initial 10 minutes of monitoring (see multiple range test, Table 3).

2. Alewife

2.1 Typical Behavioural Patterns

Alewife response included "direct passage", "avoidance", and "accumulation" behaviours (Figure 2). Fish accumulation was also observed in control tests but not to the same extent as observed with bubbles present.

2.2 Effect of Bubble Size and Horizontal Spacing on Alewife Behaviour

2.2.1 Low Level Light Tests

Passages - Results and Discussion

All experimental data were standardized relative to each set of corresponding controls. The number of alewife passages was found to vary with the hole opening (Figure 3, $F_{3,48} = 8.9$, $p < 0.05$, Appendix A). Results of a multiple range test indicated that highest reductions occurred for hole openings in the bubble wand of 1.3 and 5.0 cm (Table 4). Relative to control tests, the effectiveness of a 5.0 cm diameter hole opening in excluding fish ranged from 73% for a bubble spacing of 20 cm to 90% for bubbles spaced 10 cm apart (see Appendix A for actual percentages). For all spacings combined, mean effectiveness of the 5.0 cm hole opening was 84%. The lowest reduction occurred for a hole opening of 0.6 cm (Figure 3). Mean effectiveness was less than 20% relative to control tests.

In these tests, it is suspected that fish avoidance is related not only to the size of bubble immediately following release but possibly also to the size of the area covered by the rising bubbles and/or frequency at which bubbles are emitted. Unfortunately, we have almost no data to verify the importance of these latter components. It is noteworthy, however, that the bubble barrier which was shown to be effective in earlier laboratory tests (Ontario Hydro Research Division Report No 82-362-K) consisted of small bubbles (<1 cm) produced from a wand several centimeters in diameter. It is probable that fish are responding to air bubbles partly as a visual one.

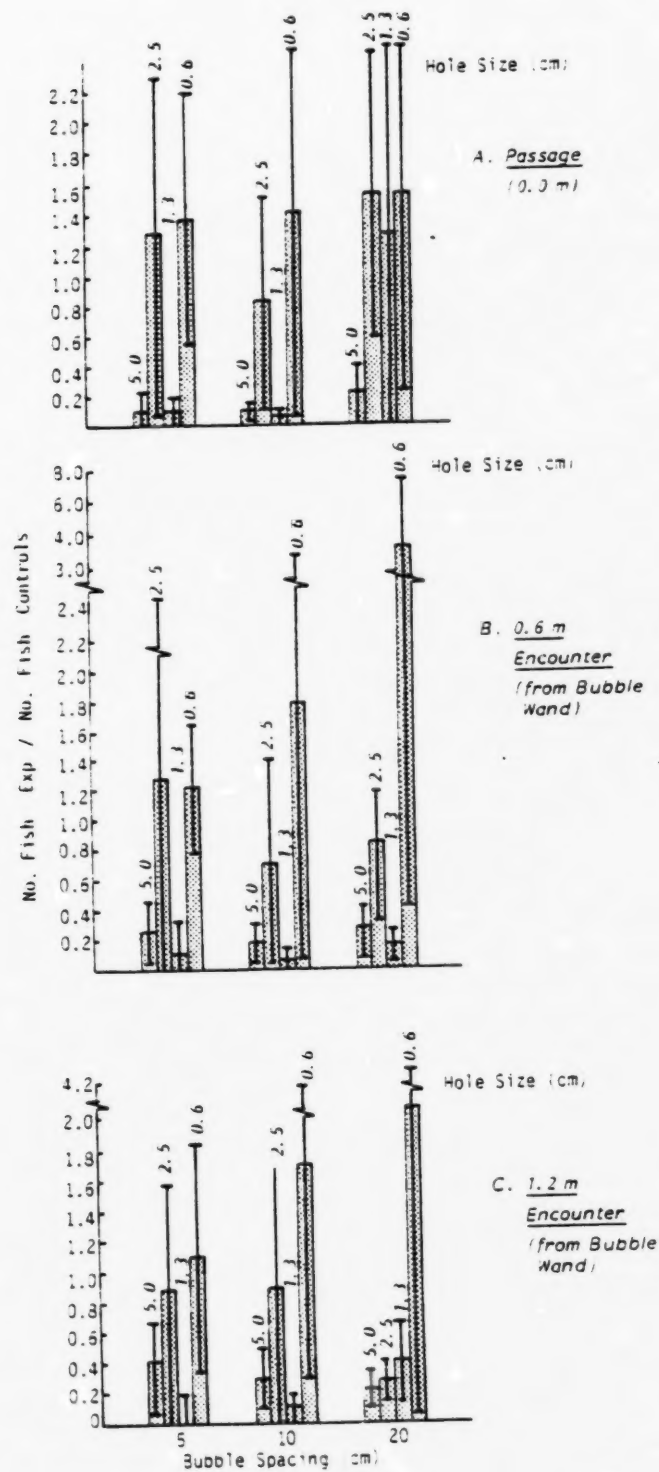


FIGURE 3
EFFECTS OF BUBBLE SIZE AND SPACING ON THE
NUMBER OF ALEWIFE PASSAGES AND ENCOUNTERS
RELATIVE TO CONTROLS (LOW LEVEL LIGHT TESTS)

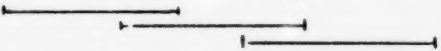
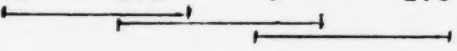
For all hole openings tested, there was no significant trend in the number of alewife passages with an increase in bubble spacing (Figure 3, $F_{2,48} = 1.22$, $p > 0.05$). These results are similar to previous air bubble work (Ontario Hydro Research Division Report No 82-362-K) where effectiveness of the bubble system did not consistently increase with decreased bubble spacing.

Encounters - Results and Discussion

Information was also obtained on the number of fish encounters 0.6 and 1.2 m from the air bubble barrier (Figure 3). Similar to the passage results, hole size significantly influenced the effectiveness of the system in reducing the number of alewife encounters (0.6 m $F_{3,48} = 14.9$, $p < 0.05$; 1.2 m $F_{3,48} = 7.6$, $p < 0.05$, Appendix B). Multiple range tests suggest that fewest encounters occurred with 1.3 and 5.0 cm openings, and highest with the 0.6 and 2.5 cm openings (Table 4). Horizontal bubble spacing was not a significant factor influencing the number of fish encounters (0.6 m $F_{2,48} = 0.8$, $p > 0.05$; 1.2 m $F_{2,48} = 0.1$, $p > 0.05$).

TABLE 4

MULTIPLE RANGE TESTS COMPARING THE ROLE OF
HOLE OPENING AS A FACTOR AFFECTING
ALEWIFE BEHAVIOUR UNDER LOW LEVEL LIGHT

<u>Comparison</u>	<u>Multiple Range (lowest → highest reduction)</u>				
Passages (0.0 m distance line)	0.79	0.69	0.21	0.14	ratio number*
	0.6	2.5	1.3	5	hole opening (cm)
					
Encounters (0.6 m distance line)	1.01	0.55	0.22	0.11	ratio number
	0.6	2.5	5	1.3	hole opening (cm)
					
Encounters (1.2 m distance line)	0.84	0.37	0.29	0.19	ratio number
	0.6	2.5	5	1.3	hole opening (cm)
					

* ratio - $\frac{\# \text{ fish experimental}}{\# \text{ fish control}}$ (transformed data)

2.2.2 Night Simulated Tests

Passages - Results and Discussion

Similar to low level light tests, the number of alewife passing through the bubble screen varied with hole opening ($F_{2,24} = 10.3$, $p < 0.05$, Figure 4, Appendix B). The interaction term, (Hole Opening x Spacing), was also significant which suggested that the rate of increase/decrease in fish passages for different hole openings varied with bubble spacing. A multiple range test shows that for bubbles spaced 5 cm apart, the highest reduction in fish passages occurred with hole openings in the bubble wand of 0.6 and 5.0 cm (Table 5). If bubbles were spaced 20 cm apart, reductions in fish passages were slightly higher with a hole opening of 1.3 cm (Table 5). Relative to controls, highest overall mean effectiveness in the night simulated tests occurred with 0.6 (49%) and 5.0 (45%) cm size openings (Appendix A).

The highest effectiveness (49%) in the night simulated tests was still 35% less effective than that recorded under low level light (highest mean effectiveness for 5.0 cm hole size, 84%). These data are consistent with earlier work on air bubbles (Ontario Hydro Research Division Report No 82-362-K), and indicate that illumination is required to increase barrier effectiveness at night or when visibility is reduced. These results are also consistent with studies conducted by Stewart (1981). Avoidance of air bubbles may therefore result from primarily visual cues, although other factors such as sound or pressure created by the bubble screen probably also play a role (Kuznetsov, 1971).

Results of the low level light tests show that the number of fish passing through 5 and 20 cm spaced bubble barriers did not vary significantly when all bubble (hole) size results are combined (Figure 4, $F_{1,24} = 1.2$, $p > 0.05$). However, when hole size results are analyzed separately, there is a noticeable decrease in effectiveness for hole openings of 0.6 and 5.0 cm with increased bubble spacing.

Encounters - Results and Discussion

Information was also obtained on the number of fish encounters 0.6 and 1.2 m from the air bubble barrier (Figure 4). Similar to the passage results, hole opening was a significant variable influencing the number of fish encounters (0.6 m $F_{2,24} = 12.5$, $p < 0.05$; 1.2 m $F_{2,24} = 12.5$, $p < 0.05$). The interaction term (Hole Opening x Spacing) was also significant for each distance line (Appendix B). Multiple range tests showed that generally the highest number of encounters was noted for a hole opening of 1.3 cm (Table 5). The only exception was the 0.6 m encounter results (20 cm spaced bubbles) where the highest number of encounters occurred with a hole opening of 5.0 cm. Bubble spacing did not significantly influence the number of fish encounters at 0.6 and 1.2 m distance lines (0.6 m $F_{1,24} = 0.0$, $p > 0.05$; 1.2 m $F_{1,24} = 0.1$, $p > 0.05$, Appendix B).

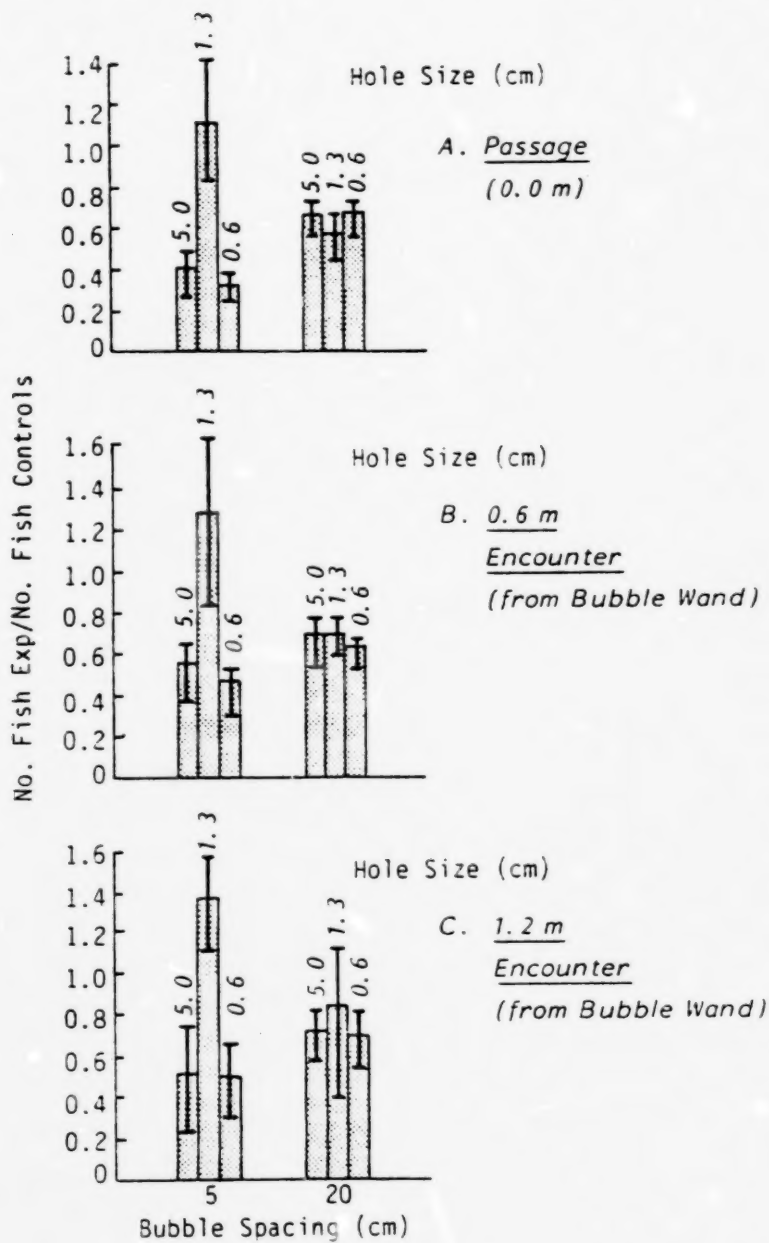


FIGURE 4
EFFECTS OF BUBBLE SIZE AND SPACING ON THE
NUMBER OF ALEWIFE PASSAGES AND ENCOUNTERS
RELATIVE TO CONTROLS (NIGHT SIMULATED TESTS)

TABLE 5

MULTIPLE RANGE TESTS COMPARING THE ROLE OF
HOLE OPENING AS A FACTOR AFFECTING
ALEWIFE BEHAVIOUR UNDER SIMULATED NIGHT CONDITIONS

<u>Comparison</u>	<u>Bubble Spacing (cm)</u>	<u>Multiple Range (lowest + highest reduction)</u>			
Passages (0.0 m distance line)	5	0.76	0.33	0.28	ratio number*
		1.3	5.0	0.6	hole opening (cm)
	20	0.53	0.53	0.45	ratio number
		5.0	0.6	1.3	hole opening (cm)
Encounters (0.6 m distance line)	5	0.84	0.43	0.38	ratio number
		1.3	5.0	0.6	hole opening (cm)
	20	0.56	0.54	0.54	ratio number
		5.0	1.3	0.6	hole opening (cm)
Encounters (1.2 m distance line)	5	0.84	0.44	0.36	ratio number
		1.3	5.0	0.6	hole opening (cm)
	20	0.59	0.56	0.54	ratio number
		1.3	5.0	0.6	hole opening (cm)

* ratio - $\frac{\# \text{ fish experimental}}{\# \text{ fish control}}$ (transformed data)

Overall, effectiveness of air bubbles in excluding fish is probably somewhat lower than that achieved for a rope-net barrier (Ontario Hydro Research Division Report No 81-190-K). Highest overall effectiveness achieved (84%, 5 cm bubble openings, low level light) was still less than that observed with a rope-net barrier (Ontario Hydro Research Division Report No 81-190-K).

2.3 Time Interval at Which Passages and Encounters Occurred - Results and Discussion

Data were analyzed with respect to the time interval (0,5,10,15, 20,25,30 minutes) at which most alewife passages and encounters occurred during both low level light and simulated night conditions (Table 6). In the low level light tests the rate at which alewife passages and encounters occurred did not vary significantly over the monitoring period. Analysis of the night simulated data indicated a similar trend with one exception. For a hole opening of 5.0 cm, spaced 5 cm apart, the highest number of passages appeared to occur in the initial 10 minutes of monitoring.

These results are significant when one considers that a barrier system must be effective for fish approaching the system for the first time. Still, these results are only preliminary given the short duration of experimental tests.

2.4 Effectiveness of a Combined Light/Air Bubble Screen in Fish Exclusion

Compared to air bubbles alone (night simulated tests), all light sources were effective in reducing the number of alewife passages when combined with air bubbles (0.6 cm hole opening, 5 cm spacing, Figure 5). Mean effectiveness in reducing the number of alewife passages ranged from approximately 88% for both red filtered and white incandescent light sources to 82% for filtered blue incandescent sources. These estimates were significantly higher than observed with air bubbles alone (effectiveness of 67%, $F_{3,16} = 9.8$, $p < 0.05$, Appendices A&C). With the addition of light, mean effectiveness of this bubble configuration was increased up to 21%. Lights combined with air bubbles were also compared with respect to the number of alewife encounters 0.6 and 1.2 m from the bubble wand (relative to air bubbles alone). Results of ANOVA and multiple range test (Appendix C) confirmed that red filtered and white incandescent light sources were the most effective in reducing the number of fish encounters at the 0.6 m distance line ($F_{3,16} = 4.9$, $p < 0.05$, Appendix C). No significant difference between light types and bubbles alone was evident at the 1.2 m distance line ($F_{3,16} = 2.5$, $p < 0.05$).

TABLE 6

RESULTS OF ANALYSES OF VARIANCE STATISTICS
 COMPARING MEAN TIME AT WHICH MOST ALEWIFE PASSAGES
 (0.0 m) AND ENCOUNTERS (0.6, 1.2m) OCCURRED FOR EACH TEST CONDITION

A. LOW LEVEL LIGHT

Comparison	hole opening (cm)	Bubble Spacing (cm)	d.f.	F statistic	Multiple Range Test lowest→highest numbers
Passages (0.0 m)	0.6	5	5,24	0.6	-
		10	5,24	1.1	-
		20	5,24	0.7	-
	1.3	5	5,24	0.8	-
		10	5,24	0.3	-
		20	5,24	1.3	-
	2.5	5	5,24	0.7	-
		10	5,24	0.8	-
		20	5,24	1.1	-
	5.0	5	5,24	0.4	-
		10	5,24	1.5	-
		20	5,24	0.3	-
0.6 m distance line	0.6	5	5,24	0.4	-
		10	5,24	1.0	-
		20	5,24	0.9	-
	1.3	5	5,24	0.8	-
		10	5,24	0.7	-
		20	5,24	1.0	-
	2.5	5	5,24	0.8	-
		10	5,24	0.5	-
		20	5,24	1.1	-
	5.0	5	5,24	0.3	-
		10	5,24	1.0	-
		20	5,24	0.2	-
1.2 m distance line	0.6	5	5,24	0.1	-
		10	5,24	0.6	-
		20	5,24	0.3	-
	1.3	5	5,24	0.8	-
		10	5,24	1.5	-
		20	5,24	1.0	-
	2.5	5	5,24	0.5	-
		10	5,24	0.2	-
		20	5,24	0.9	-
	5.0	5	5,24	0.5	-
		10	5,24	1.6	-
		20	5,24	0.4	-

TABLE 6 (cont'd)

B. NIGHT SIMULATED

<u>Comparison</u>	<u>Bubble Size (cm)</u>	<u>Bubble Spacing (cm)</u>	<u>d.f.</u>	<u>F statistic</u>	<u>Multiple Range Test lowest, highest numbers</u>
Passages (0.0 m)	0.6	5	5,24	0.4	-
		20	5,24	0.8	-
	1.3	5	5,24	0.9	-
		20	5,24	1.3	-
	5.0	5	5,24	2.7*	30 25 15 20 10 5
		20	5,24	1.5	-
Encounters (0.6 m distance line)	0.6	5	5,24	0.3	-
		20	5,24	0.6	-
	1.3	5	5,24	0.8	-
		20	5,24	0.6	-
	5.0	5	5,24	1.0	-
		20	5,24	1.3	-
Encounters (1.2 m distance line)	0.6	5	5,24	0.4	-
		20	5,24	1.0	-
	1.3	5	5,24	0.8	-
		20	5,24	0.3	-
	5.0	5	5,24	1.0	-
		20	5,24	1.2	-

Time
(min)

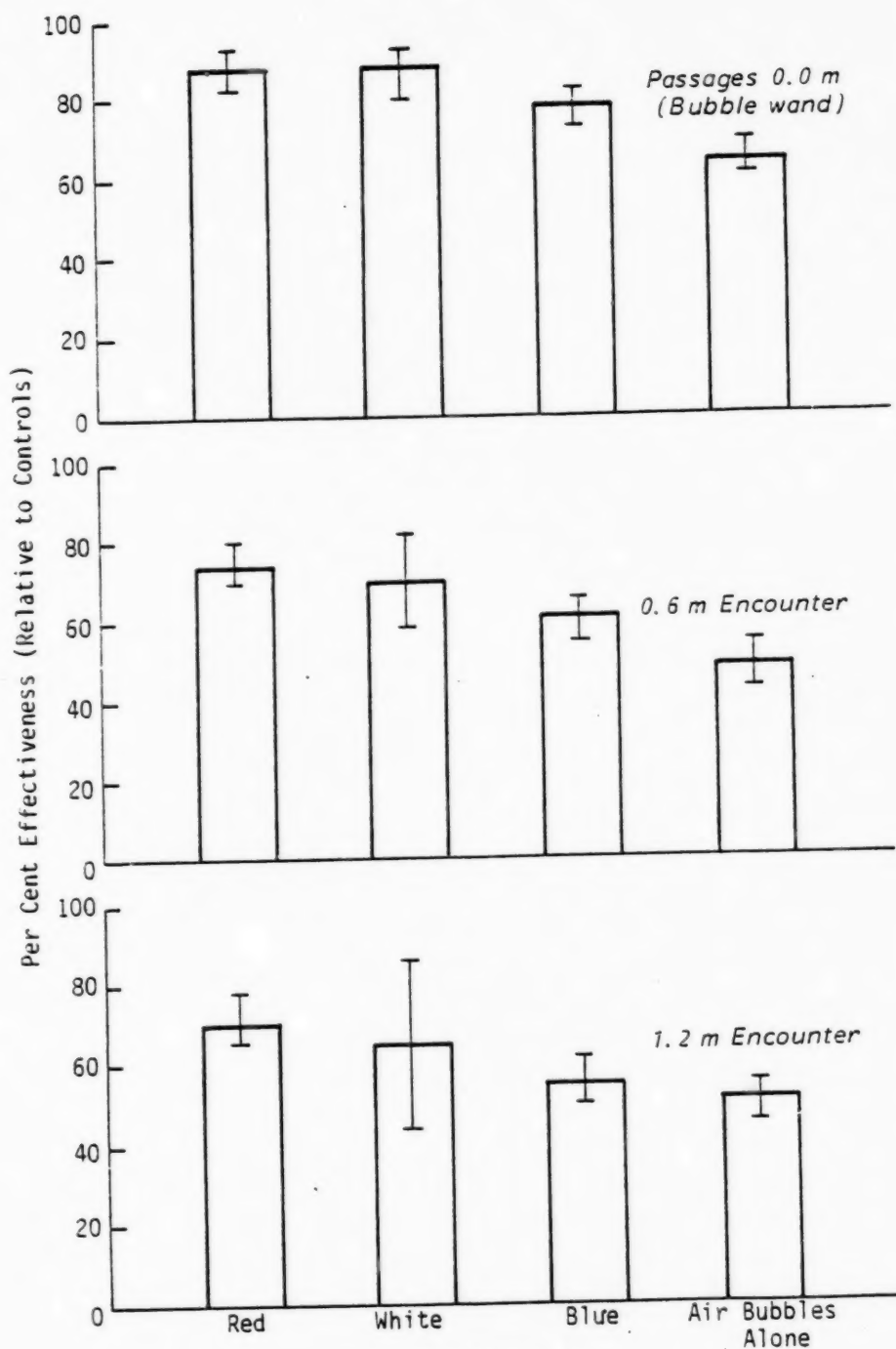


FIGURE 5
COMPARISON OF EFFECTIVENESS BETWEEN
RED, WHITE AND BLUE INCANDESCENT LIGHT
WHEN COMBINED WITH AIR BUBBLES IN EXCLUDING ALEWIFE
(0.6cm HOLE OPENING, 5cm SPACING)

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The effectiveness of adding various light sources to a bubble wand of 5 cm opening spaced 20 cm apart was examined (Figure 6). A combined white strobe light/air bubble scheme was also included for comparison. Relative to air bubbles alone (30% effective), all light sources were effective in reducing the number of fish passages when combined with air bubbles ($F_{4,20} = 24.7$ $p < 0.05$, Appendix C). Effectiveness was highest for white incandescent (90%) and strobe (84%) light sources, followed by red (75%) and blue (62%) light types. The addition of light to this air bubble configuration increased its effectiveness as a fish excluder in excess of 45%. A multiple range test confirmed that highest effectiveness was achieved using both white incandescent and strobe light sources (Table 7). The blue filtered test results were not significantly different than air bubbles alone. There were also significant differences in the number of encounters 0.6 and 1.2 m from the bubble wand among the lights relative to bubbles alone (0.6 m $F_{4,20} = 17.6$, $p < 0.05$; 1.2 m $F_{4,20} = 28.0$, $p < 0.05$). Multiple range tests suggested that strobe and white incandescent were the most effective light types.

TABLE 7

MULTIPLE RANGE TESTS COMPARING THE EFFECTIVENESS
OF RED (R), BLUE (B) AND WHITE (W) INCANDESCENT,
AND STROBE (S) LIGHT COMBINED WITH AIR
BUBBLES TO BUBBLES ALONE (BA) IN EXCLUDING FISH

Comparison	Multiple Range (lowest→highest effectiveness)					
Passages (0.0 m distance line)	0.53	0.31	0.22	0.13	0.09	ratio number*
	BA	B	R	S	W	light source
Encounters (0.6 m distance line)	0.55	0.51	0.33	0.20	0.18	ratio number
	BA	B	R	S	W	light source
Encounters (1.2 m distance line)	0.56	0.55	0.34	0.25	0.23	ratio number
	BA	B	R	W	S	light source

* ratio - $\frac{\# \text{ fish experimental}}{\# \text{ fish control}}$ (transformed data)

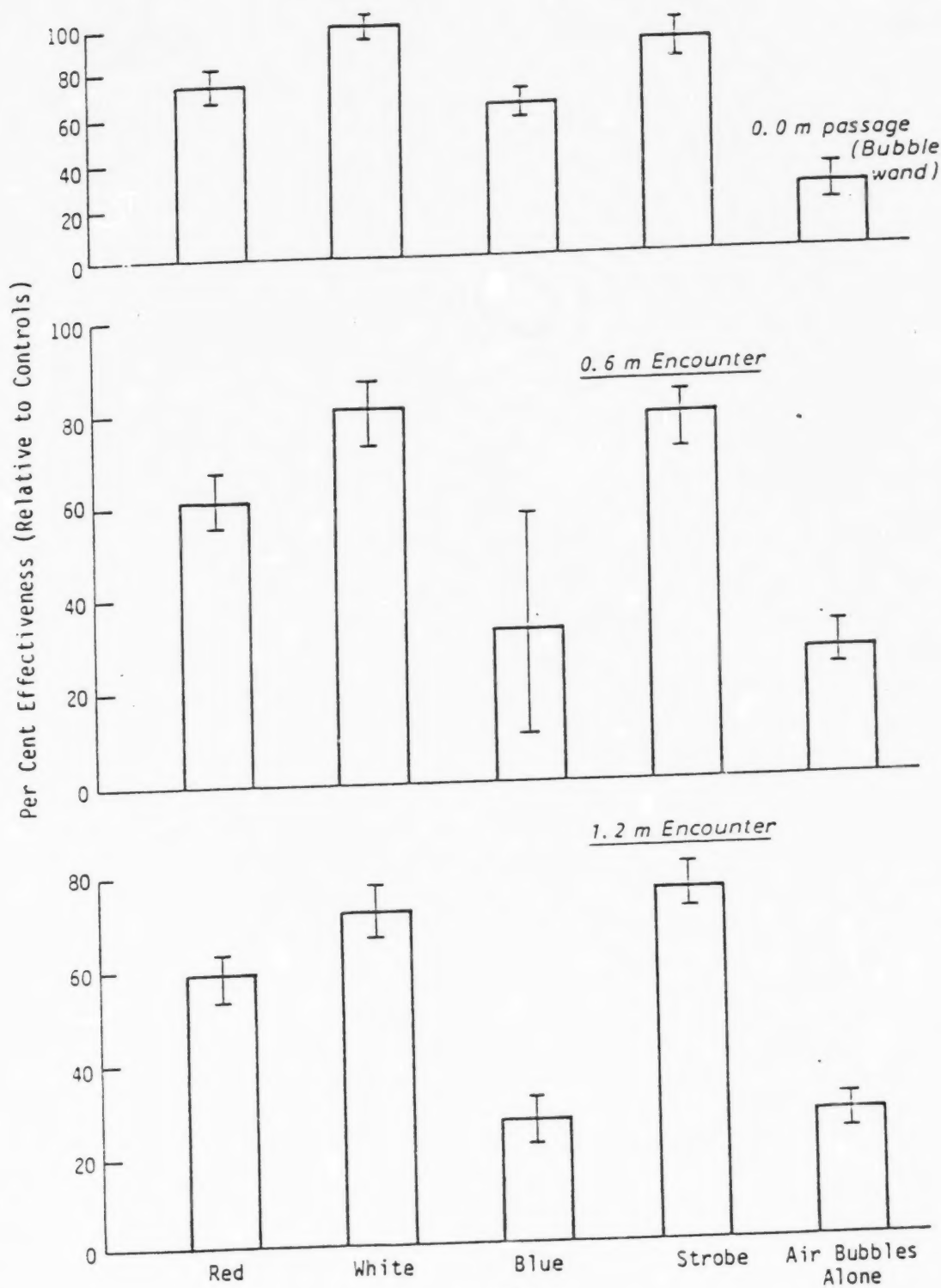


FIGURE 6

COMPARISON OF EFFECTIVENESS BETWEEN RED, WHITE AND BLUE INCANDESCENT, AND STROBE LIGHT WHEN COMBINED WITH AIR BUBBLES IN EXCLUDING ALEWIFE (5.0cm HOLE OPENING, 20cm SPACING)

Data were also analyzed to determine whether there was an increase or decrease in numbers (either passages or encounters) as the monitoring period progressed (Table 8). The blue filtered light results were all significant and suggested that after 5 minutes of illumination there was a significant increase in fish numbers. These results suggest an initial attraction. There was no statistical evidence of attraction to red filtered, white or strobe light (except strobe passage results).

Effectiveness of air bubbles in reducing the number of fish passages was increased when illuminated. The objective of using lights is simply to illuminate the barrier using low level light (<5 lux, $<0.01 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$) so that fish can perceive it (ie not using light as a deterrent or attractant). The consistently higher effectiveness of white incandescent over blue incandescent (Figures 5 & 6) is expected. Fish avoidance of light is both a function of light quality (wave length) and quantity (intensity). Pelagic species such as alewife tend to prefer or attract to the shorter wave lengths of light (eg blue in this case; Ontario Hydro Research Division Report No 82-288-K), and avoid or are repelled by the longer wave lengths (eg red; Ontario Hydro Research Division Report No 78-516-K; Ben-Yami, 1976). White incandescent, like red, contains a large portion of its energy in the orange and red regions of the visible spectrum (597-735 nm, Bickford and Dunn, 1972) which fish tend to avoid (Ontario Hydro Research Division Report No 78-516-K). The intensity of white light in these tests was considerably higher than that of red light, resulting in an increased avoidance of this light source (Figure 6). However, if red light intensities were similar to those of white light, a similar avoidance response may occur. White incandescent and strobe lights were similar in effectiveness, although light intensity was considerably higher in the white incandescent tests.

CONCLUSIONS

1. The responses of fish to air bubbles and lights were investigated under laboratory conditions. For alewife, effectiveness of the bubble screen under low level light varied with size in hole opening in the bubble wand. The highest effectiveness in reducing the number of fish passages through the bubble barrier occurred with hole openings of 5.0 and 1.3 cm. The size of hole opening did not appear to significantly influence smelt behaviour. For both alewife and smelt, bubble (horizontal) spacing did not play a significant role affecting barrier effectiveness.
2. For both alewife and smelt there was no indication of either increased passages and/or encounters of the bubble screen as the monitoring period progressed.

TABLE 8

RESULTS OF ANALYSES OF VARIANCE STATISTICS COMPARING THE MEAN TIME INTERVAL AT WHICH MOST ALEWIFE PASSAGES (0.0 m) AND ENCOUNTERS (0.6, 1.2 m) OCCURRED FOR EACH LIGHT TEST

Bubble Size and Spacing (cm)	Light Type	Comparison	d.f.	F-statistic	Multiple Range Test (lowest-highest numbers)	time (min)
0.6 cm openings spaced 5.0 cm apart	Red	Passages	5,24	1.9	-	-
		0.6 m encounters	5,24	0.9	-	-
		1.2 m encounters	5,24	1.1	-	-
	Blue	Passages	5,24	1.61*	5 10 15 30 25 20	time (min)
		0.6 m encounters	5,24	5.8*	5 15 25 30 10 20	time (min)
		1.2 m encounters	5,24	3.1*	5 15 25 30 10 20	time (min)
	White	Passages	5,24	1.8	-	-
		0.6 m encounters	5,24	0.6	-	-
		1.2 m encounters	5,24	0.6	-	-
5.0 cm openings spaced 20 cm apart	Red	Passages	5,24	0.9	-	-
		0.6 m encounters	5,24	0.6	-	-
		1.2 m encounters	5,24	0.3	-	-
	Blue	Passages	5,24	1.19*	5 10 15 20 25 30	time (min)
		0.6 m encounters	5,24	5.2*	5 10 15 20 25 30	time (min)
		1.2 m encounters	5,24	5.6*	5 15 10 20 25 30	time (min)
	White	Passages	5,24	2.5	-	-
		0.6 m encounters	5,24	1.9	-	-
		1.2 m encounters	5,24	1.3	-	-
	Strobe	Passages	5,24	6.2*	5 10 15 20 30 25	time (min)
		0.6 m encounters	5,24	1.9	-	-
		1.2 m encounters	5,24	2.1	-	-

* sig at $p < 0.05$
 $F_{5,24} =$

3. In alewife tests, air bubbles were generally less effective in the absence of light, suggesting that illumination is required to increase its effectiveness at night or when visibility is reduced. Night simulated tests were only conducted with alewife. Preliminary tests with light indicated that white and red filtered incandescent light may offer attractive alternatives to strobe light when combined with air bubbles as an exclusion scheme.

RECOMMENDATIONS

1. For application in the field it is recommended that size of bubble opening and/or area of coverage be maximized, and that the bubble screen be continuous. This may be of importance especially since fish are probably responding to air bubbles as a visual cue.
2. Although laboratory experiments showed no indication of either increased fish passages and/or encounters of the bubble screen, these data should be treated as preliminary since the test duration was only 30 minutes. For field application, it is recommended that field tests be of longer duration (eg 12 h) to take into account possible acclimation effects.
3. Results indicate that bubbles should be illuminated to increase their effectiveness at night or when visibility is reduced. For field application, it is suggested that lights be placed on the bottom and be projected vertically rather than horizontally. This will limit the potential for far-field attraction. Fish attraction to white (or red filtered) incandescent light in the field is still expected to occur (even though short term tests of 30 minutes' duration did not suggest acclimation). This is, however, not expected to be of major significance in application in a forebay, but may be of concern at an intake installation. The objective of using light in a forebay application is simply to illuminate the barrier using low level light so that fish can perceive it (ie not as a deterrent or attractant).
4. An obvious advantage of air bubbles over other systems (eg barrier-nets) is that the bubble screen will not be readily fouled by material in the water column (algae, frazil ice) and would therefore be preferred in certain locations.

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APPENDIX A

ANALYSIS OF VARIANCE (TWO-WAY) COMPARING THE ROLES OF BUBBLE SIZE AND SPACING IN AFFECTING SMELT PASSAGES AND ENCOUNTERS (LOG TRANSFORMED DATA)

1. Passages (0.0 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	<u>F-ratio</u>
Bubble	2	2.80	1.40	1.33
Space	1	0.19	0.19	0.18
Interaction	2	4.93	2.46	2.34
Within	24	25.27	1.05	

2. Encounters (0.6 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	<u>F-ratio</u>
Bubble	2	1.24	0.62	0.6
Space	1	0.19	0.19	0.2
Interaction	2	2.45	1.22	1.12
Within	24	26.22	1.09	

3. Encounters (1.2 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	<u>F-ratio</u>
Bubble	2	4.56	2.28	2.36
Space	1	1.14	1.14	1.18
Interaction	2	3.55	1.78	1.84
Within	24	23.20	0.97	

APPENDIX A

COMPARISON OF THE MEAN NUMBER OF SMELT PASSAGES
(0.0 m) AND ENCOUNTERS (0.6, 1.2 m DISTANCE LINES)
FOR VARIOUS HOLE OPENINGS AND SPACINGS

	Hole Opening (cm)					
	0.6		2.5		5.0	
	Spacing (cm)		Spacing (cm)		Spacing (cm)	
	5	20	5	20	5	20
Passages	27.8 (47.8) *	39.6 (25.1)	14.8 (3.6)	13.8 (20.7)	20.0 (17.6)	25.4 (20.9)
Encounters (0.6 m)	68.4 (94.0)	49.2 (28.9)	35.8 (18.4)	22.4 (25.9)	43.6 (53.7)	28.8 (20.5)
Encounters (1.2 m)	87.0 (76.8)	67.4 (41.6)	50.8 (21.5)	21.2 (26.6)	38.0 (38.6)	30.6 (20.8)

*indicates S.D. (x)

APPENDIX A (cont'd)

PER CENT EFFECTIVENESS OF VARIOUS AIR BUBBLE
SIZES AND SPACINGS IN EXCLUDING ALEWIFE

<u>Light Condition</u>	<u>Bubble Size (cm)</u>	<u>Bubble Spacing (cm)</u>	<u>Mean Effectiveness (per cent)</u>
Low level light	0.6	5	} not effective*
		10	
		20	
	1.3	5	87
		10	94
		20	not effective
	2.5	5	not effective
		10	21
		20	not effective
	5.0	5	88
		10	90
		20	73 84 (average)
Night simulated	0.6	5	67
		20	31 49 (average)
	1.3	5	not effective
		20	42
	5.0	5	60
		20	30 45 (average)

* less than 20% effective

APPENDIX B

ANALYSIS OF VARIANCE (TWO-WAY) COMPARING THE ROLES OF BUBBLE SIZE AND SPACING AS AFFECTING ALEWIFE PASSAGES AND ENCOUNTERS (LOG TRANSFORMED DATA)

I. LOW LEVEL LIGHT TESTS

1. Passages (0.0 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	<u>F-ratio</u>
Bubble	3	4.96	1.65	8.88*
Space	2	0.57	0.29	1.54
Interaction	6	0.18	0.05	0.25
Within	48	8.93	0.19	

* sig at $p < 0.05$

2. Encounters (0.6 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	<u>F-ratio</u>
Bubble	3	7.46	2.49	14.89*
Space	2	0.28	0.14	0.84
Interaction	6	0.58	0.10	0.57
Within	48	8.01	0.17	

* sig at $p < 0.05$

3. Encounters (1.2 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	<u>F-ratio</u>
Bubble	3	3.74	1.25	7.65*
Space	2	0.05	0.03	0.15
Interaction	6	0.54	0.09	0.55
Within	48	7.8	0.16	

* sig at $p < 0.05$

APPENDIX B (cont'd)

II. NIGHT SIMULATED TESTS

1. Passages (0.0 m distance line)

Source	Analysis of Variance Table			
	d.f.	s.s.	m.s.	F-ratio
Bubble	2	0.24	0.12	10.31*
Space	1	0.01	0.01	1.25
Interaction	2	0.48	0.24	20.95*
Within	24	0.27	0.01	

* sig at $p < 0.05$

2. Encounters (0.6 m distance line)

Source	Analysis of Variance Table			
	d.f.	s.s.	m.s.	F-ratio
Bubble	2	0.32	0.16	12.50*
Space	1	0.00	0.00	0.00
Interaction	2	0.32	0.16	12.72*
Within	24	0.30	0.01	

* sig at $p < 0.05$

3. Encounters (1.2 m distance line)

Source	Analysis of Variance Table			
	d.f.	s.s.	m.s.	F-ratio
Bubble	2	0.39	0.20	12.48*
Space	1	0.00	0.00	0.14
Interaction	2	0.28	0.14	8.96*
Within	24	0.38	0.02	

* sig at $p < 0.05$

APPENDIX C

ANALYSIS OF VARIANCE (ONE-WAY) COMPARING THE EFFECTIVENESS OF COMBINING LIGHT (RED, WHITE, BLUE, INCANDESCENT; STROBE) WITH AIR BUBBLES AS AN EXCLUSION SCHEME

I. 0.6 cm bubbles, spaced 5 cm apart

1. Passages (0.0 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			<u>F-ratio</u>
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	
Light	3	0.09	0.03	9.83*
Within	16	0.05	0.00	
Total	19	0.14		

2. Encounters (0.6 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			<u>F-ratio</u>
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	
Light	3	0.09	0.03	4.97*
Within	16	0.10	0.01	
Total	19	0.19		

3. Encounters (1.2 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			<u>F-ratio</u>
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	
Light	3	0.06	0.02	2.47
Within	16	0.12	0.01	
Total	19	0.18		

* sig at $p < 0.05$

APPENDIX C (cont'd)

II. 5.0 cm bubbles, spaced 20 cm apart.

1. Passages (0.0 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			<u>F-ratio</u>
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	
Light	4	0.51	0.13	24.7*
Within	20	0.10	0.01	
Total	24	0.62		

2. Encounters (0.6 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			<u>F-ratio</u>
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	
Light	4	0.58	0.14	17.56*
Within	20	0.16	0.01	
Total	24	0.74		

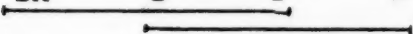
3. Encounters (1.2 m distance line)

<u>Source</u>	<u>Analysis of Variance Table</u>			<u>F-ratio</u>
	<u>d.f.</u>	<u>s.s.</u>	<u>m.s.</u>	
Light	4	0.60	0.15	28.04*
Within	20	0.10	0.01	
Total	24	0.70		

* sig $p < 0.05$

APPENDIX C

MULTIPLE RANGE TESTS COMPARING THE EFFECTIVENESS OF RED(R), BLUE(B) AND WHITE INCANDESCENT(I) LIGHT COMBINED WITH AIR BUBBLES TO BUBBLES ALONE(BA) IN EXCLUDING FISH

<u>Comparison</u>	<u>Multiple Range (lowest+highest reduction)</u>				
Passages (0.0 m distance line)	0.28	0.18	0.12	0.12	fish ratio*
	BA	B	I	R	light source
					
Encounters (0.6 m distance line)	0.38	0.32	0.24	0.21	fish ratio
	BA	B	I	R	light source
					
Encounters (1.2 m distance line)	No significant difference				fish ratio
					light source

* ratio = $\frac{\# \text{ fish experimental}}{\# \text{ fish control}}$ (transformed data)

APPENDIX D

RAW DATA

SMELT - LOW LEVEL LIGHT

BUBBLE SIZE	SPAC- ING	DIST. LINE	TIME (MIN)						TOTAL
			5	10	15	20	25	30	
.25	2	1	3	1	1	2	2	4	13
.25	2	2	5	1	1	2	2	4	15
.25	2	3	3	2	1	2	2	3	13
.25	2	1	85	35	58	8	0	4	190
.25	2	2	18	71	71	18	18	28	224
.25	2	3	2	39	20	25	16	11	113
.25	2	1	72	17	33	11	1	0	134
.25	2	2	41	14	9	12	9	6	91
.25	2	3	0	0	0	0	1	3	4
.25	2	1	1	0	32	15	25	11	84
.25	2	2	4	1	1	0	1	0	7
.25	2	3	1	3	1	0	1	0	6
.25	2	1	0	11	3	0	0	0	14
.25	2	2	0	2	3	0	0	0	5
.25	2	3	0	1	2	0	0	0	3
.25	8	1	5	5	4	3	3	3	23
.25	8	2	5	6	3	3	3	3	23
.25	8	3	4	4	3	2	3	3	19
.25	8	1	8	13	18	16	28	16	99
.25	8	2	7	8	11	11	17	8	62
.25	8	3	7	6	10	9	13	7	52
.25	8	1	3	3	5	4	11	10	36
.25	8	2	3	5	5	6	2	3	24
.25	8	3	3	4	3	2	3	0	15
.25	8	1	8	8	14	8	6	14	58
.25	8	2	5	11	10	3	9	7	45
.25	8	3	2	5	9	9	9	2	36
.25	8	1	16	12	13	18	33	29	121
.25	8	2	12	16	14	11	20	19	92
.25	8	3	14	11	14	5	17	15	76
1	2	1	4	10	1	3	2	1	21
1	2	2	3	11	1	3	2	1	21
1	2	3	3	1	1	3	2	1	11
1	2	1	4	20	1	5	5	1	36
1	2	2	3	12	1	5	4	1	26
1	2	3	3	1	1	3	4	1	13
1	2	1	39	17	4	4	3	5	72
1	2	2	19	34	5	3	2	4	67
1	2	3	6	4	2	3	2	3	20
1	2	1	30	2	21	4	1	2	60
1	2	2	19	1	1	4	1	2	28
1	2	3	9	1	1	4	1	1	17
1	2	1	33	17	2	7	4	2	65
1	2	2	8	19	3	2	4	1	37
1	2	3	0	3	2	2	5	1	13
1	8	1	1	1	0	0	0	0	2
1	8	2	5	1	0	0	0	0	6
1	8	3	0	1	0	0	0	0	1
1	8	1	3	0	0	0	0	0	3
1	8	2	2	0	0	0	0	0	2
1	8	3	0	0	0	0	0	0	0
1	8	1	9	1	4	2	1	1	18

BUBBLE SIZE	SPAC- ING	DIST. LINE	TIME (MIN)						TOTAL
			5	10	15	20	25	30	
1	8	2	21	1	2	3	1	1	29
1	8	3	0	1	2	3	1	1	8
1	8	1	46	7	5	4	2	3	67
1	8	2	40	10	6	4	3	2	65
1	8	3	32	3	6	4	3	2	50
1	8	1	1	6	1	3	2	3	16
1	8	2	1	1	1	3	2	2	10
1	8	3	1	1	1	3	2	2	10
2	2	1	0	1	0	0	1	3	5
2	2	2	0	1	0	0	1	4	6
2	2	3	0	1	0	0	1	2	4
2	2	1	28	20	26	5	7	14	100
2	2	2	35	11	31	24	20	15	136
2	2	3	7	6	8	8	7	11	47
2	2	1	11	7	10	5	5	2	40
2	2	2	16	5	6	4	5	4	40
2	2	3	2	4	6	4	5	4	25
2	2	1	0	0	2	1	2	1	6
2	2	2	0	0	2	1	3	1	7
2	2	3	0	0	1	2	1	1	5
2	2	1	12	8	2	2	3	12	39
2	2	2	11	4	2	2	3	7	29
2	2	3	3	2	2	2	3	7	19
2	8	1	3	8	7	8	13	6	45
2	8	2	5	9	7	6	12	6	45
2	8	3	5	8	7	6	11	6	43
2	8	1	11	7	12	12	8	10	60
2	8	2	10	8	11	9	8	10	56
2	8	3	10	8	9	9	8	9	53
2	8	1	2	1	1	0	4	4	12
2	8	2	2	1	1	0	4	2	10
2	8	3	1	1	1	0	3	3	9
2	8	1	5	1	2	3	2	6	19
2	8	2	3	1	3	6	2	5	20
2	8	3	1	1	2	3	2	4	13
2	8	1	0	2	4	2	3	6	17
2	8	2	0	2	3	2	1	5	13
2	8	3	0	1	3	1	0	4	9

ALEWIFE - NIGHT SIMULATED

CON/ EXP	REP	BUBBLE SIZE	SPACING	DIST. LINE	TIME (MIN)						TOTAL
					5	10	15	20	25	30	
CON	1	.5	0	1	173	156	147	168	156	157	957
CON	1	.5	0	2	173	156	147	169	156	157	958
CON	1	.5	0	3	169	154	147	164	156	155	945
CON	2	.5	0	1	205	249	275	274	254	242	1499
CON	2	.5	0	2	206	254	278	277	258	243	1516
CON	2	.5	0	3	204	251	275	275	258	240	1503
CON	3	.5	0	1	209	199	207	215	223	201	1254
CON	3	.5	0	2	215	201	209	218	228	205	1276
CON	3	.5	0	3	209	200	210	218	224	203	1264
CON	4	.5	0	1	198	232	217	176	182	203	1208
CON	4	.5	0	2	200	224	216	178	176	206	1200
CON	4	.5	0	3	172	203	206	174	165	204	1124
CON	5	.5	0	1	183	190	181	179	193	201	1127
CON	5	.5	0	2	186	184	181	180	177	202	1110
CON	5	.5	0	3	175	174	171	175	190	197	1082
CON	6	.5	0	1	185	198	206	199	221	197	1206
CON	6	.5	0	2	188	197	209	202	220	199	1215
CON	6	.5	0	3	186	196	206	199	222	196	1205
CON	7	.5	0	1	218	258	302	301	326	317	1722
CON	7	.5	0	2	218	256	300	300	325	317	1716
CON	7	.5	0	3	208	254	293	295	324	315	1689
CON	8	.5	0	1	243	261	242	249	255	228	1478
CON	8	.5	0	2	244	262	241	248	255	227	1477
CON	8	.5	0	3	238	258	240	246	253	227	1462
CON	9	.5	0	1	145	164	156	201	196	206	1068
CON	9	.5	0	2	146	164	154	205	198	202	1069
CON	9	.5	0	3	140	162	152	199	193	200	1046
CON	10	.5	0	1	180	205	209	213	211	215	1233
CON	10	.5	0	2	175	205	209	212	212	221	1234
CON	10	.5	0	3	171	204	208	211	213	213	1220
EXP	1	.5	2	1	246	293	311	280	282	257	1669
EXP	1	.5	2	2	248	298	310	280	281	257	1674
EXP	1	.5	2	3	204	276	300	272	273	234	1559
EXP	2	.5	2	1	206	218	232	243	261	242	1402
EXP	2	.5	2	2	202	217	232	243	260	243	1397
EXP	2	.5	2	3	148	173	210	221	237	228	1217
EXP	3	.5	2	1	258	252	270	243	269	278	1570
EXP	3	.5	2	2	261	254	272	248	268	276	1579
EXP	3	.5	2	3	246	248	261	237	257	266	1515
EXP	4	.5	2	1	119	159	249	297	292	247	1363
EXP	4	.5	2	2	117	159	243	288	291	242	1340
EXP	4	.5	2	3	82	107	162	177	217	183	928
EXP	5	.5	2	1	359	274	242	304	334	346	1859
EXP	5	.5	2	2	352	270	229	303	334	332	1820
EXP	5	.5	2	3	271	220	191	254	272	248	1456
EXP	6	.5	8	1	92	102	103	99	101	117	614
EXP	6	.5	8	2	86	98	102	101	104	116	607
EXP	6	.5	8	3	66	65	80	79	89	102	481
EXP	7	.5	8	1	90	103	106	131	134	155	719
EXP	7	.5	8	2	90	111	103	132	134	154	724
EXP	7	.5	8	3	53	69	63	86	109	132	512
EXP	8	.5	8	1	236	236	189	261	315	273	1510

CON/ EXP	REP	BUBBLE SIZE	SPACING	DIST. LINE	5	10	TIME (MIN)				25	30	TOTAL
							15	20					
EXP	8	.5	8	2	199	180	166	209	232	223	1209		
EXP	8	.5	8	3	128	120	133	121	124	166	792		
EXP	9	.5	8	1	160	173	194	132	158	171	988		
EXP	9	.5	8	2	142	169	186	139	155	170	961		
EXP	9	.5	8	3	103	154	179	119	134	156	845		
EXP	10	.5	8	1	211	242	270	255	313	265	1556		
EXP	10	.5	8	2	160	191	221	236	287	249	1344		
EXP	10	.5	8	3	88	126	152	204	250	227	1047		
CON	1	2	0	1	185	186	202	225	226	228	1252		
CON	1	2	0	2	187	188	203	228	225	229	1260		
CON	1	2	0	3	178	182	202	222	223	228	1235		
CON	2	2	0	1	189	197	213	227	238	242	1306		
CON	2	2	0	2	198	195	217	231	238	246	1325		
CON	2	2	0	3	191	196	213	227	238	242	1307		
CON	3	2	0	1	304	327	322	359	340	343	1995		
CON	3	2	0	2	284	317	320	353	335	336	1945		
CON	3	2	0	3	270	305	310	344	333	235	1797		
CON	4	2	0	1	202	222	232	230	247	247	1380		
CON	4	2	0	2	201	224	232	236	247	247	1387		
CON	4	2	0	3	201	222	226	230	246	247	1372		
CON	5	2	0	1	289	356	339	336	417	394	2131		
CON	5	2	0	2	288	354	340	337	417	394	2130		
CON	5	2	0	3	289	354	337	337	417	394	2128		
CON	6	2	0	1	199	205	219	239	260	244	1366		
CON	6	2	0	2	200	207	222	239	261	244	1373		
CON	6	2	0	3	199	204	221	238	257	242	1361		
CON	7	2	0	1	200	242	240	243	236	246	1407		
CON	7	2	0	2	197	243	240	243	237	248	1408		
CON	7	2	0	3	194	244	237	242	236	246	1399		
CON	8	2	0	1	246	270	393	357	359	336	1961		
CON	8	2	0	2	244	270	393	346	359	339	1951		
CON	8	2	0	3	238	267	342	339	359	339	1884		
CON	9	2	0	1	236	244	257	255	263	256	1511		
CON	9	2	0	2	239	245	257	255	263	257	1516		
CON	9	2	0	3	237	244	257	253	265	255	1511		
CON	10	2	0	1	210	209	206	228	228	230	1311		
CON	10	2	0	2	211	208	206	228	228	229	1310		
CON	10	2	0	3	210	206	203	227	228	227	1301		
EXP	1	2	2	1	114	161	180	174	188	184	1001		
EXP	1	2	2	2	107	147	176	173	185	183	971		
EXP	1	2	2	3	56	82	101	95	121	136	591		
EXP	2	2	2	1	148	152	185	174	184	176	1019		
EXP	2	2	2	2	145	145	184	174	184	175	1007		
EXP	2	2	2	3	92	104	122	140	159	147	764		
EXP	3	2	2	1	99	110	126	123	135	141	734		
EXP	3	2	2	2	98	116	128	113	135	143	733		
EXP	3	2	2	3	75	89	113	91	118	122	608		
EXP	4	2	2	1	78	88	87	101	89	104	547		
EXP	4	2	2	2	77	85	86	92	79	97	516		
EXP	4	2	2	3	48	60	64	67	61	76	376		
EXP	5	2	2	1	134	149	153	181	158	170	945		
EXP	5	2	2	2	131	140	150	174	158	166	919		
EXP	5	2	2	3	75	107	120	121	135	116	674		
EXP	6	2	8	1	208	193	175	170	202	196	1144		

CON/ EXP	REP	BUBBLE SIZE	SPACING	DIST. LINE	TIME (MIN)						TOTAL
					5	10	15	20	25	30	
EXP	6	2	8	2	202	193	179	169	203	197	1143
EXP	6	2	8	3	176	180	174	166	187	189	1072
EXP	7	2	8	1	118	196	190	193	202	212	1111
EXP	7	2	8	2	117	194	189	189	199	212	1100
EXP	7	2	8	3	86	182	179	172	186	209	1014
EXP	8	2	8	1	223	202	195	199	216	206	1241
EXP	8	2	8	2	222	202	195	198	217	205	1239
EXP	8	2	8	3	213	200	187	191	212	198	1201
EXP	9	2	8	1	155	163	152	189	190	188	1037
EXP	9	2	8	2	157	160	147	189	189	186	1028
EXP	9	2	8	3	134	139	119	181	171	185	929
EXP	10	2	8	1	176	166	159	187	185	191	1064
EXP	10	2	8	2	173	168	157	186	183	190	1057
EXP	10	2	8	3	160	157	147	174	172	174	984
CON	1	.25	0	1	146	178	158	132	151	108	873
CON	1	.25	0	2	146	178	159	134	150	111	878
CON	1	.25	0	3	144	175	152	128	144	107	850
CON	2	.25	0	1	171	179	184	215	210	206	1165
CON	2	.25	0	2	170	177	184	215	209	203	1158
CON	2	.25	0	3	165	174	179	210	207	200	1135
CON	3	.25	0	1	211	217	248	209	241	232	1358
CON	3	.25	0	2	211	215	247	209	240	232	1354
CON	3	.25	0	3	207	213	246	206	236	230	1338
CON	4	.25	0	1	153	175	204	183	179	207	1101
CON	4	.25	0	2	152	174	202	184	178	207	1097
CON	4	.25	0	3	149	171	200	183	180	198	1081
CON	5	.25	0	1	184	184	194	224	190	199	1175
CON	5	.25	0	2	182	184	190	221	187	199	1163
CON	5	.25	0	3	172	182	185	220	184	194	1137
EXP	1	.25	2	1	113	70	82	69	84	83	501
EXP	1	.25	2	2	104	75	76	82	79	86	502
EXP	1	.25	2	3	39	28	40	45	46	54	252
EXP	2	.25	2	1	75	74	71	81	74	85	460
EXP	2	.25	2	2	58	61	69	87	85	82	442
EXP	2	.25	2	3	44	42	49	59	55	53	302
EXP	3	.25	2	1	79	65	36	62	46	42	330
EXP	3	.25	2	2	90	92	73	68	104	57	484
EXP	3	.25	2	3	58	64	54	60	86	50	372
EXP	4	.25	2	1	93	78	90	91	77	95	524
EXP	4	.25	2	2	101	75	91	89	85	87	528
EXP	4	.25	2	3	67	51	63	66	59	77	383
EXP	5	.25	2	1	91	95	108	106	93	102	595
EXP	5	.25	2	2	101	100	106	105	96	106	614
EXP	5	.25	2	3	79	81	93	88	87	91	519
CON	6	.25	0	1	155	118	117	135	163	126	814
CON	6	.25	0	2	175	122	118	136	169	133	853
CON	6	.25	0	3	166	118	118	135	165	130	832
CON	7	.25	0	1	161	156	173	173	185	159	1007
CON	7	.25	0	2	147	153	164	171	178	153	966
CON	7	.25	0	3	139	143	149	165	175	152	923
CON	8	.25	0	1	149	169	148	196	152	149	963
CON	8	.25	0	2	158	178	152	201	152	153	994
CON	8	.25	0	3	158	174	152	199	150	154	987
CON	9	.25	0	1	167	172	197	178	198	187	1099

CON/ EXP	REP	BUBBLE SIZE	SPACING	DIST. LINE	5	10	TIME (MIN)				25	30	TOTAL
							15	20					
CON	9	.25	0	2	165	166	193	175	192	186			1077
CON	9	.25	0	3	161	167	193	177	189	181			1068
CON	10	.25	0	1	141	135	115	156	135	122			804
CON	10	.25	0	2	143	139	120	159	131	127			819
CON	10	.25	0	3	138	136	121	155	128	132			810
EXP	6	.25	8	1	94	87	112	118	124	127			662
EXP	6	.25	8	2	97	93	122	117	123	127			673
EXP	6	.25	8	3	88	86	103	114	116	119			626
EXP	7	.25	8	1	122	133	120	123	115	99			712
EXP	7	.25	8	2	117	130	117	122	107	100			693
EXP	7	.25	8	3	110	117	107	115	107	89			645
EXP	8	.25	8	1	103	135	103	145	127	120			733
EXP	8	.25	8	2	110	133	107	150	133	116			749
EXP	8	.25	8	3	106	129	105	143	130	114			727
EXP	9	.25	8	1	109	101	79	112	85	113			599
EXP	9	.25	8	2	113	101	85	110	91	107			607
EXP	9	.25	8	3	103	98	68	96	88	105			558
EXP	10	.25	8	1	77	112	120	111	110	113			643
EXP	10	.25	8	2	80	109	122	104	116	116			647
EXP	10	.25	8	3	76	106	118	99	111	119			629

ALEWIFE - LOW LEVEL LIGHT

CON/ EXP	REP	BUBBLE SIZE	SPACING	DIST. LINE	TIME (MIN)						TOTAL
					5	10	15	20	25	30	
CON	1	2	0	1	44	50	90	75	59	74	392
CON	1	2	0	2	38	38	92	73	56	70	367
CON	1	2	0	3	38	33	70	54	46	58	299
CON	2	2	0	1	25	62	73	38	52	109	359
CON	2	2	0	2	27	67	70	45	41	82	332
CON	2	2	0	3	24	66	65	33	36	90	314
CON	3	2	0	1	197	107	123	108	166	73	774
CON	3	2	0	2	145	59	92	82	138	62	578
CON	3	2	0	3	67	64	73	48	106	38	396
CON	4	2	0	1	53	84	29	51	57	82	356
CON	4	2	0	2	46	39	42	50	39	64	280
CON	4	2	0	3	38	25	44	36	39	47	229
CON	5	2	0	1	66	18	26	24	18	10	162
CON	5	2	0	2	67	12	22	21	13	6	141
CON	5	2	0	3	63	13	26	23	12	4	141
CON	6	2	0	1	53	46	62	7	27	33	228
CON	6	2	0	2	50	42	51	10	30	32	215
CON	6	2	0	3	51	42	54	15	31	39	232
CON	7	2	0	1	177	145	149	131	132	109	843
CON	7	2	0	2	139	138	135	144	154	111	821
CON	7	2	0	3	121	114	120	136	130	47	668
CON	8	2	0	1	95	105	86	120	121	72	599
CON	8	2	0	2	76	83	104	121	124	90	598
CON	8	2	0	3	84	83	89	120	128	82	586
CON	9	2	0	1	172	177	150	93	132	131	855
CON	9	2	0	2	108	120	119	107	95	102	651
CON	9	2	0	3	108	120	118	91	109	92	638
CON	10	2	0	1	20	28	87	86	71	99	391
CON	10	2	0	2	17	29	71	83	71	99	370
CON	10	2	0	3	15	27	71	83	71	99	366
EXP	1	2	8	1	7	4	22	21	33	35	122
EXP	1	2	8	2	1	3	8	10	45	19	86
EXP	1	2	8	3	1	3	1	1	21	11	38
EXP	2	2	8	1	1	3	1	5	4	2	16
EXP	2	2	8	2	0	3	2	4	8	6	23
EXP	2	2	8	3	0	3	2	5	10	4	24
EXP	3	2	8	1	28	12	9	14	34	3	100
EXP	3	2	8	2	7	1	3	11	9	4	35
EXP	3	2	8	3	1	1	1	2	0	2	7
EXP	4	2	8	1	65	34	30	7	13	11	160
EXP	4	2	8	2	63	46	32	10	13	9	173
EXP	4	2	8	3	54	34	21	11	14	8	142
EXP	5	2	8	1	7	6	15	8	7	8	51
EXP	5	2	8	2	15	8	20	8	7	8	66
EXP	5	2	8	3	15	7	19	8	11	10	70
EXP	6	2	2	1	68	42	22	43	52	28	255
EXP	6	2	2	2	24	38	20	33	21	23	159
EXP	6	2	2	3	17	23	10	22	10	10	92
EXP	7	2	2	1	28	47	34	30	26	40	205
EXP	7	2	2	2	39	33	28	16	17	23	156
EXP	7	2	2	3	23	15	11	6	8	0	63
EXP	8	2	2	1	35	11	32	5	10	10	103

CON/ EXP	REP	BUBBLE SIZE	SPACING	DIST. LINE	TIME (MIN)						TOTAL
					5	10	15	20	25	30	
EXP	8	2	2	2	20	2	17	2	8	4	53
EXP	8	2	2	3	7	0	4	2	3	2	18
EXP	9	2	2	1	36	5	38	14	39	38	170
EXP	9	2	2	2	16	0	10	4	10	18	58
EXP	9	2	2	3	0	0	2	0	0	3	5
EXP	10	2	2	1	19	54	52	45	55	0	225
EXP	10	2	2	2	9	24	22	21	47	2	125
EXP	10	2	2	3	0	6	5	0	19	2	32
EXP	6	2	4	1	62	27	34	21	36	12	192
EXP	6	2	4	2	8	17	15	16	22	6	84
EXP	6	2	4	3	5	9	7	8	16	6	51
EXP	7	2	4	1	34	71	27	44	38	14	228
EXP	7	2	4	2	22	33	15	36	21	6	133
EXP	7	2	4	3	13	23	8	21	8	4	77
EXP	8	2	4	1	11	27	24	61	20	5	148
EXP	8	2	4	2	4	7	14	31	9	0	65
EXP	8	2	4	3	4	4	7	20	4	0	39
EXP	9	2	4	1	53	22	11	5	2	1	94
EXP	9	2	4	2	8	10	4	5	2	2	31
EXP	9	2	4	3	1	5	4	3	2	2	17
EXP	10	2	4	1	32	32	32	18	35	26	175
EXP	10	2	4	2	15	22	22	12	29	25	125
EXP	10	2	4	3	6	11	6	6	9	5	43
CON	1	1	0	1	15	25	9	12	18	7	86
CON	1	1	0	2	12	14	6	10	16	9	67
CON	1	1	0	3	7	10	6	8	16	9	56
CON	2	1	0	1	80	21	55	28	7	22	213
CON	2	1	0	2	25	8	10	12	6	10	71
CON	2	1	0	3	2	7	8	8	6	7	38
CON	3	1	0	1	35	21	33	36	28	14	167
CON	3	1	0	2	9	4	17	10	8	10	58
CON	3	1	0	3	6	3	8	8	8	10	43
CON	4	1	0	1	102	62	29	8	32	25	258
CON	4	1	0	2	46	11	8	3	14	6	88
CON	4	1	0	3	37	2	8	3	9	6	65
CON	5	1	0	1	58	66	52	34	100	70	380
CON	5	1	0	2	27	63	52	28	95	70	335
CON	5	1	0	3	7	48	52	29	82	69	287
EXP	1	1	2	1	53	14	34	96	128	2	327
EXP	1	1	2	2	55	11	29	106	123	2	326
EXP	1	1	2	3	36	3	14	76	105	2	236
EXP	2	1	2	1	32	0	2	1	2	46	83
EXP	2	1	2	2	36	0	2	2	2	30	72
EXP	2	1	2	3	18	0	3	3	3	28	55
EXP	3	1	2	1	5	6	0	2	0	1	14
EXP	3	1	2	2	11	6	2	2	0	2	23
EXP	3	1	2	3	16	4	2	2	0	5	29
EXP	4	1	2	1	3	0	1	1	0	0	5
EXP	4	1	2	2	2	0	1	2	0	0	5
EXP	4	1	2	3	3	0	1	1	0	0	5
EXP	5	1	2	1	57	4	2	7	4	3	77
EXP	5	1	2	2	74	6	3	14	6	5	108
EXP	5	1	2	3	46	7	5	16	6	6	86
EXP	1	1	4	1	84	108	41	34	6	65	338

CON/ EXP	REP	BUBBLE SIZE	SPACING	DIST. LINE	TIME (MIN)						TOTAL
					5	10	15	20	25	30	
EXP	1	1	4	2	15	36	29	36	8	48	172
EXP	1	1	4	3	15	13	14	36	3	42	123
EXP	2	1	4	1	0	0	0	0	0	4	4
EXP	2	1	4	2	4	2	0	0	0	7	13
EXP	2	1	4	3	1	2	2	1	1	7	14
EXP	3	1	4	1	0	2	1	0	3	3	9
EXP	3	1	4	2	0	3	5	1	3	6	18
EXP	3	1	4	3	1	2	5	1	7	7	23
EXP	4	1	4	1	4	3	7	2	3	10	29
EXP	4	1	4	2	4	4	7	2	5	12	34
EXP	4	1	4	3	3	4	8	2	5	12	34
EXP	5	1	4	1	9	5	20	22	24	20	100
EXP	5	1	4	2	11	8	19	23	22	18	101
EXP	5	1	4	3	11	7	18	24	23	16	99
EXP	1	1	8	1	5	4	8	4	20	1	42
EXP	1	1	8	2	9	9	15	9	20	5	67
EXP	1	1	8	3	21	18	19	13	22	11	104
EXP	2	1	8	1	2	2	5	4	12	8	33
EXP	2	1	8	2	5	2	8	4	13	7	39
EXP	2	1	8	3	14	8	13	11	17	15	78
EXP	3	1	8	1	11	13	5	9	21	5	64
EXP	3	1	8	2	14	11	7	4	22	5	63
EXP	3	1	8	3	20	12	6	7	24	4	73
EXP	4	1	8	1	24	25	13	6	29	16	113
EXP	4	1	8	2	17	25	9	9	36	17	113
EXP	4	1	8	3	15	17	13	11	36	21	113
EXP	5	1	8	1	10	5	17	19	3	8	62
EXP	5	1	8	2	8	10	18	25	2	4	67
EXP	5	1	8	3	12	9	20	23	4	7	75
EXP	1	.25	8	1	20	15	10	22	30	2	99
EXP	1	.25	8	2	8	20	4	8	18	0	58
EXP	1	.25	8	3	4	7	1	1	11	0	24
EXP	2	.25	8	1	14	2	11	14	8	6	55
EXP	2	.25	8	2	1	2	10	8	4	0	25
EXP	2	.25	8	3	0	0	1	4	1	0	6
EXP	3	.25	8	1	7	2	1	4	46	37	97
EXP	3	.25	8	2	3	1	4	4	18	27	57
EXP	3	.25	8	3	3	1	4	4	3	16	31
EXP	4	.25	8	1	32	42	53	51	49	51	278
EXP	4	.25	8	2	1	8	9	5	9	20	52
EXP	4	.25	8	3	1	0	3	0	2	4	10
EXP	5	.25	8	1	8	16	20	20	4	8	76
EXP	5	.25	8	2	7	2	6	7	4	11	37
EXP	5	.25	8	3	3	1	1	3	4	5	17
EXP	6	.25	4	1	53	36	30	17	48	64	248
EXP	6	.25	4	2	14	45	16	12	12	23	122
EXP	6	.25	4	3	3	20	4	8	0	10	45
EXP	7	.25	4	1	36	23	6	5	9	2	81
EXP	7	.25	4	2	47	18	11	5	9	2	92
EXP	7	.25	4	3	23	14	9	3	8	2	59
EXP	8	.25	4	1	15	39	0	41	42	5	142
EXP	8	.25	4	2	7	36	0	38	38	2	121
EXP	8	.25	4	3	5	29	0	17	27	1	79
EXP	9	.25	4	1	18	1	20	2	3	0	44

CON/ EXP	REP	BUBBLE SIZE	SPACING	DIST. LINE	TIME (MIN)						TOTAL
					5	10	15	20	25	30	
EXP	9	.25	4	2	10	0	9	1	0	0	20
EXP	9	.25	4	3	1	0	2	0	0	0	3
EXP	10	.25	4	1	17	59	42	18	38	8	182
EXP	10	.25	4	2	19	23	30	7	23	3	105
EXP	10	.25	4	3	11	11	17	5	6	1	51
EXP	6	.25	2	1	44	27	22	12	11	12	128
EXP	6	.25	2	2	21	17	7	5	7	1	58
EXP	6	.25	2	3	0	12	0	0	4	0	16
EXP	7	.25	2	1	9	4	11	3	13	13	53
EXP	7	.25	2	2	11	4	5	6	13	10	49
EXP	7	.25	2	3	9	7	6	8	13	15	58
EXP	8	.25	2	1	4	19	2	7	9	15	56
EXP	8	.25	2	2	9	15	2	5	11	15	57
EXP	8	.25	2	3	6	17	3	5	9	14	54
EXP	9	.25	2	1	39	34	38	20	35	20	186
EXP	9	.25	2	2	25	12	36	11	18	17	119
EXP	9	.25	2	3	13	12	24	7	13	11	80
EXP	10	.25	2	1	2	21	17	42	22	14	118
EXP	10	.25	2	2	3	16	21	13	13	11	77
EXP	10	.25	2	3	0	5	18	8	6	3	40
CON	1	.25	0	1	29	37	62	38	6	9	181
CON	1	.25	0	2	31	20	15	8	1	3	78
CON	1	.25	0	3	30	2	3	2	1	3	41
CON	2	.25	0	1	17	45	74	18	23	11	188
CON	2	.25	0	2	1	19	29	7	18	7	81
CON	2	.25	0	3	1	9	10	6	18	6	50
CON	3	.25	0	1	11	0	7	10	1	2	31
CON	3	.25	0	2	0	0	1	4	0	2	7
CON	3	.25	0	3	0	0	1	4	0	2	7
CON	4	.25	0	1	7	30	1	12	0	3	53
CON	4	.25	0	2	1	2	1	0	0	3	7
CON	4	.25	0	3	1	2	1	0	0	3	7
CON	5	.25	0	1	2	11	29	1	4	3	50
CON	5	.25	0	2	2	2	3	1	3	1	12
CON	5	.25	0	3	2	2	2	1	3	1	11
CON	6	.25	0	1	4	12	5	2	27	15	65
CON	6	.25	0	2	4	6	5	2	17	9	43
CON	6	.25	0	3	4	6	3	2	17	8	40
CON	7	.25	0	1	70	28	32	36	21	15	202
CON	7	.25	0	2	39	4	11	4	6	10	74
CON	7	.25	0	3	17	4	6	4	3	7	41
CON	8	.25	0	1	33	18	23	12	6	9	101
CON	8	.25	0	2	4	5	10	4	5	4	32
CON	8	.25	0	3	1	4	6	2	4	3	20
CON	9	.25	0	1	50	31	20	30	13	4	148
CON	9	.25	0	2	34	15	15	26	8	3	101
CON	9	.25	0	3	7	4	6	19	4	3	43
CON	10	.25	0	1	50	0	5	0	3	17	75
CON	10	.25	0	2	50	0	4	0	1	18	73
CON	10	.25	0	3	51	0	4	0	1	17	73
CON	1	.5	0	1	13	1	1	6	13	8	42
CON	1	.5	0	2	13	1	1	5	12	7	39
CON	1	.5	0	3	14	2	1	5	12	9	43
CON	2	.5	0	1	2	5	9	9	15	13	53

CON/ EXP	REP	BUBBLE SIZE	SPACING	DIST. LINE	TIME (MIN)						TOTAL
					5	10	15	20	25	30	
CON	2	.5	0	2	3	5	8	8	16	12	52
CON	2	.5	0	3	3	5	8	8	16	12	52
CON	3	.5	0	1	2	41	32	87	66	46	274
CON	3	.5	0	2	2	37	34	64	51	54	242
CON	3	.5	0	3	2	37	30	61	51	54	235
CON	4	.5	0	1	95	37	27	39	27	31	256
CON	4	.5	0	2	71	22	18	20	12	16	159
CON	4	.5	0	3	65	19	15	16	11	14	140
CON	5	.5	0	1	19	19	18	6	8	13	83
CON	5	.5	0	2	6	5	5	5	8	8	37
CON	5	.5	0	3	6	3	4	5	8	8	34
CON	6	.5	0	1	52	57	7	3	52	21	192
CON	6	.5	0	2	57	40	0	0	13	2	112
CON	6	.5	0	3	57	36	0	0	0	0	93
CON	7	.5	0	1	21	4	19	2	12	9	67
CON	7	.5	0	2	3	0	15	1	4	1	24
CON	7	.5	0	3	0	0	7	1	4	1	13
CON	8	.5	0	1	2	41	18	6	8	29	104
CON	8	.5	0	2	0	37	14	6	0	11	68
CON	8	.5	0	3	0	6	0	7	0	1	14
CON	9	.5	0	1	15	15	14	13	25	20	102
CON	9	.5	0	2	20	18	27	27	26	28	146
CON	9	.5	0	3	2	0	0	0	0	0	2
CON	10	.5	0	1	30	2	0	2	1	1	36
CON	10	.5	0	2	42	1	0	1	2	1	47
CON	10	.5	0	3	26	1	0	1	1	1	30
EXP	1	.5	2	1	7	2	3	2	1	1	16
EXP	1	.5	2	2	12	4	4	3	1	1	25
EXP	1	.5	2	3	13	5	3	3	1	1	26
EXP	2	.5	2	1	0	0	1	0	0	0	1
EXP	2	.5	2	2	0	0	1	0	0	0	1
EXP	2	.5	2	3	0	0	1	0	0	0	1
EXP	3	.5	2	1	1	14	0	0	0	0	15
EXP	3	.5	2	2	1	12	0	0	0	0	13
EXP	3	.5	2	3	1	9	0	0	0	0	10
EXP	4	.5	2	1	1	0	0	1	0	0	2
EXP	4	.5	2	2	0	0	0	1	0	0	1
EXP	4	.5	2	3	0	0	0	1	0	0	1
EXP	5	.5	2	1	0	0	0	0	0	0	0
EXP	5	.5	2	2	0	0	0	0	0	0	0
EXP	5	.5	2	3	0	0	0	0	0	0	0
EXP	6	.5	4	1	0	5	0	0	0	0	5
EXP	6	.5	4	2	0	0	0	0	0	0	0
EXP	6	.5	4	3	0	0	0	0	0	0	0
EXP	7	.5	4	1	5	1	0	0	0	0	6
EXP	7	.5	4	2	0	1	0	0	0	0	1
EXP	7	.5	4	3	0	1	0	0	0	0	1
EXP	8	.5	4	1	2	0	0	17	0	0	19
EXP	8	.5	4	2	2	0	0	2	0	0	4
EXP	8	.5	4	3	2	0	0	0	0	0	2
EXP	9	.5	4	1	0	0	0	0	0	0	0
EXP	9	.5	4	2	0	0	0	0	0	0	0
EXP	9	.5	4	3	0	0	0	0	0	0	0
EXP	10	.5	4	1	0	0	1	8	3	0	12

CON/ EXP	REP	BUBBLE SIZE	SPACING	DIST. LINE	TIME (MIN)						TOTAL
					5	10	15	20	25	30	
EXP	10	.5	4	2	0	0	5	4	2	0	11
EXP	10	.5	4	3	0	0	1	1	1	0	3
EXP	6	.5	8	1	58	0	1	0	1	2	62
EXP	6	.5	8	2	33	0	0	0	1	2	36
EXP	6	.5	8	3	31	0	0	0	1	2	34
EXP	7	.5	8	1	11	5	2	1	7	6	32
EXP	7	.5	8	2	0	0	0	1	3	3	7
EXP	7	.5	8	3	0	0	0	0	0	0	0
EXP	8	.5	8	1	2	5	0	0	2	2	11
EXP	8	.5	8	2	2	0	0	0	1	0	3
EXP	8	.5	8	3	1	0	0	0	0	0	1
EXP	9	.5	8	1	1	21	21	4	20	11	78
EXP	9	.5	8	2	1	1	0	4	7	5	18
EXP	9	.5	8	3	1	0	0	4	4	2	11
EXP	10	.5	8	1	8	16	3	0	0	3	30
EXP	10	.5	8	2	2	1	1	0	0	0	4
EXP	10	.5	8	3	1	0	1	0	0	0	2

ALEWIFE - AIR BUBBLES/LIGHT

CON/ EXP	LIGHT	BUBBLE SIZE	SPAC- ING	REP	DIST. LINE	5	10	TIME (MIN)		25	30	TOTAL
								15	20			
CON	I	.25	0	1	1	152	149	163	145	161	142	912
CON	I	.25	0	1	2	148	144	165	143	159	137	896
CON	I	.25	0	1	3	152	146	164	147	158	146	913
CON	I	.25	0	2	1	159	184	182	153	154	148	980
CON	I	.25	0	2	2	172	186	188	172	161	156	1035
CON	I	.25	0	2	3	172	178	187	171	160	156	1024
CON	I	.25	0	3	1	202	211	187	217	201	239	1257
CON	I	.25	0	3	2	191	202	178	216	192	228	1207
CON	I	.25	0	3	3	175	203	180	211	192	221	1182.
CON	I	.25	0	4	1	160	194	296	202	259	206	1317
CON	I	.25	0	4	2	164	196	302	203	268	201	1334
CON	I	.25	0	4	3	160	193	300	202	265	201	1321
CON	I	.25	0	5	1	213	249	259	214	215	231	1381
CON	I	.25	0	5	2	208	244	258	209	205	211	1335
CON	I	.25	0	5	3	209	249	261	209	209	219	1356
EXP	I	.25	2	1	1	51	65	50	83	67	75	391
EXP	I	.25	2	1	2	55	61	45	65	56	67	349
EXP	I	.25	2	1	3	14	19	17	26	24	27	127
EXP	I	.25	2	2	1	61	62	92	91	83	103	492
EXP	I	.25	2	2	2	50	38	71	78	61	86	384
EXP	I	.25	2	2	3	10	27	47	47	41	50	222
EXP	I	.25	2	3	1	57	98	118	118	98	98	587
EXP	I	.25	2	3	2	39	83	81	102	81	112	498
EXP	I	.25	2	3	3	10	43	53	60	45	74	285
EXP	I	.25	2	4	1	33	40	32	32	32	27	196
EXP	I	.25	2	4	2	14	19	17	18	14	21	103
EXP	I	.25	2	4	3	2	8	9	9	10	13	51
EXP	I	.25	2	5	1	9	39	33	32	40	27	180
EXP	I	.25	2	5	2	9	22	28	36	44	26	165
EXP	I	.25	2	5	3	5	5	7	10	18	10	55
EXP	R	.25	2	1	1	29	41	46	50	46	43	255
EXP	R	.25	2	1	2	16	32	34	30	40	37	189
EXP	R	.25	2	1	3	6	12	22	23	22	22	107
EXP	R	.25	2	2	1	32	45	43	34	36	60	250
EXP	R	.25	2	2	2	37	42	63	37	26	40	245
EXP	R	.25	2	2	3	17	19	34	18	15	22	125
EXP	R	.25	2	3	1	60	73	71	66	71	84	425
EXP	R	.25	2	3	2	41	69	69	71	51	60	361
EXP	R	.25	2	3	3	16	31	33	44	38	44	206
EXP	R	.25	2	4	1	46	54	45	45	50	56	296
EXP	R	.25	2	4	2	44	49	41	27	46	45	252
EXP	R	.25	2	4	3	15	18	20	16	23	15	107
EXP	R	.25	2	5	1	50	57	65	43	51	59	325
EXP	R	.25	2	5	2	55	75	63	40	50	48	331
EXP	R	.25	2	5	3	21	39	37	24	36	31	188
EXP	B	.25	2	1	1	68	85	78	72	71	88	462
EXP	B	.25	2	1	2	45	85	76	71	67	81	425
EXP	B	.25	2	1	3	12	33	40	31	32	35	183
EXP	B	.25	2	2	1	38	95	63	69	68	88	421
EXP	B	.25	2	2	2	17	71	39	52	50	73	302
EXP	B	.25	2	2	3	5	33	26	35	43	45	187
EXP	B	.25	2	3	1	33	86	80	101	65	65	430

CON/ EXP	LIGHT	BUBBLE SIZE	SPAC- ING	REP	DIST. LINE	5	10	TIME (MIN)				25	30	TOTAL
								15	20					
EXP	B	.25	2	3	2	20	78	82	92	79	83	434		
EXP	B	.25	2	3	3	7	36	43	54	52	40	232		
EXP	B	.25	2	4	1	62	86	93	98	140	95	574		
EXP	B	.25	2	4	2	40	80	91	93	126	76	506		
EXP	B	.25	2	4	3	7	36	43	54	52	40	232		
EXP	B	.25	2	5	1	79	96	107	121	113	116	632		
EXP	B	.25	2	5	2	63	86	91	102	99	120	561		
EXP	B	.25	2	5	3	22	52	62	75	63	77	351		
CON	I	2	8	1	1	110	134	134	170	184	185	704		
CON	I	2	8	1	2	112	139	137	171	185	187	700		
CON	I	2	8	1	3	107	137	133	171	186	180	666		
CON	I	2	8	2	1	152	163	139	123	110	155	623		
CON	I	2	8	2	2	144	158	129	116	105	143	608		
CON	I	2	8	2	3	135	149	130	111	103	139	575		
CON	I	2	8	3	1	78	91	129	101	94	87	588		
CON	I	2	8	3	2	79	92	123	100	89	84	558		
CON	I	2	8	3	3	68	81	114	95	85	82	522		
CON	I	2	8	4	1	63	93	100	79	108	117	593		
CON	I	2	8	4	2	54	83	92	76	105	105	551		
CON	I	2	8	4	3	45	76	88	75	104	95	526		
CON	I	2	8	5	1	93	91	113	84	127	86	613		
CON	I	2	8	5	2	86	96	109	78	132	83	658		
CON	I	2	8	5	3	84	88	101	71	124	81	636		
EXP	B	2	8	1	1	42	101	64	61	85	105	458		
EXP	B	2	8	1	2	29	77	51	58	58	62	335		
EXP	B	2	8	1	3	7	28	20	22	25	22	124		
EXP	B	2	8	2	1	33	98	72	97	84	100	484		
EXP	B	2	8	2	2	25	69	71	89	70	87	411		
EXP	B	2	8	2	3	5	32	37	46	30	57	207		
EXP	B	2	8	3	1	33	89	90	74	87	137	510		
EXP	B	2	8	3	2	20	50	86	69	97	143	465		
EXP	B	2	8	3	3	6	28	47	44	65	94	284		
EXP	B	2	8	4	1	56	88	106	120	94	110	574		
EXP	B	2	8	4	2	42	91	101	127	95	127	583		
EXP	B	2	8	4	3	10	39	46	65	57	80	297		
EXP	B	2	8	5	1	33	34	39	57	61	75	299		
EXP	B	2	8	5	2	22	21	36	41	54	57	231		
EXP	B	2	8	5	3	8	11	17	31	34	41	142		
EXP	R	2	8	1	1	28	34	29	39	32	44	206		
EXP	R	2	8	1	2	26	34	33	37	29	33	192		
EXP	R	2	8	1	3	10	19	17	20	14	18	98		
EXP	R	2	8	2	1	46	69	57	61	56	54	343		
EXP	R	2	8	2	2	39	65	50	47	44	38	283		
EXP	R	2	8	2	3	16	33	28	25	28	30	160		
EXP	R	2	8	3	1	31	35	33	25	36	27	187		
EXP	R	2	8	3	2	32	35	33	43	34	24	201		
EXP	R	2	8	3	3	16	22	16	16	20	18	108		
EXP	R	2	8	4	1	46	43	44	44	46	39	262		
EXP	R	2	8	4	2	44	37	40	41	49	36	247		
EXP	R	2	8	4	3	28	27	29	31	44	26	185		
EXP	R	2	8	5	1	38	51	47	57	47	48	288		
EXP	R	2	8	5	2	41	49	48	45	38	54	275		
EXP	R	2	8	5	3	21	25	30	32	22	36	166		
EXP	I	2	8	1	1	17	37	25	18	47	49	193		

CON/ EXP	LIGHT	BUBBLE SIZE	SPAC- ING	REP	DIST. LINE	TIME (MIN)						TOTAL
						5	10	15	20	25	30	
EXP	I	2	8	1	2	3	20	11	14	35	33	116
EXP	I	2	8	1	3	1	7	6	7	15	15	51
EXP	I	2	8	2	1	21	49	44	40	44	55	253
EXP	I	2	8	2	2	11	37	26	26	33	47	180
EXP	I	2	8	2	3	4	15	15	16	22	28	100
EXP	I	2	8	3	1	39	44	25	23	15	16	162
EXP	I	2	8	3	2	26	34	27	14	9	12	122
EXP	I	2	8	3	3	8	14	13	8	5	6	54
EXP	I	2	8	4	1	12	14	27	21	25	19	118
EXP	I	2	8	4	2	5	4	5	6	17	11	48
EXP	I	2	8	4	3	1	0	2	3	10	9	25
EXP	I	2	8	4	1	5	33	19	35	45	41	178
EXP	I	2	8	4	2	3	20	13	36	38	42	152
EXP	I	2	8	5	3	2	7	6	11	12	16	54
EXP	S	2	8	1	1	28	18	17	20	22	18	123
EXP	S	2	8	1	2	18	11	19	20	24	16	108
EXP	S	2	8	1	3	4	7	12	9	12	10	54
EXP	S	2	8	2	1	12	13	25	26	34	25	135
EXP	S	2	8	2	2	8	15	17	25	25	22	112
EXP	S	2	8	2	3	2	7	12	19	20	17	77
EXP	S	2	8	3	1	31	22	31	26	28	28	166
EXP	S	2	8	3	2	25	12	18	14	31	23	123
EXP	S	2	8	3	3	10	7	15	13	20	16	81
EXP	S	2	8	4	1	26	25	27	47	29	27	181
EXP	S	2	8	4	2	19	25	26	32	28	24	154
EXP	S	2	8	4	3	8	17	19	22	20	18	104
EXP	S	2	8	5	1	22	17	34	44	40	33	190
EXP	S	2	8	5	2	23	23	40	42	39	26	193
EXP	S	2	8	5	3	7	12	27	30	32	34	142

POOR

QUALITY

ORIGINAL